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A

PRACTICAL TREATISE

ON

MINE ENGINEERING.

BY

G. C. GREENWELL, F.G.S., M. Inst. C.E., &c.,

COLLIERY VIEWER.

SECOND EDITION.

"WE ONLY DESIRE THAT ALL INTERESTED SHOULD HAVE THE POWER TO DISCRIMINATE BETWEEN SOUND AND UNSOUND VIEWS, SO FAR AS EXISTING KNOWLEDGE MAY BE AVAILABLE."

—SIR H. T. DE LA BECHE.

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MDCCCLXIX.

TO

THOMAS EMERSON FORSTER, ESQ., M. INST. C.E., &c., &c.,

COLLIERY VIEWER,

THE SECOND EDITION OF A

PRACTICAL TREATISE ON MINE ENGINEERING

IS

(BY PERMISSION)

MOST RESPECTFULLY DEDICATED

BY HIS

FORMER PUPIL.

THE READER IS REQUESTED TO MAKE THE FOLLOWING CORRECTIONS :—

PAGE 74.—For (*c*) millstone grit, *read* (*b*) millstone grit.

„ 120.—For Buropfield, *read* Burnopfield.

„ 186.—For 10·032, &c., *read* 10,032, &c.

„ 186.—For $W = \frac{2\,S \times b \times c}{12\,a}$, *read* $W = \frac{2\,S \times b \times c^2}{12\,a}$

„ 221.—For $\sqrt{231 \cdot 600\ H}$, *read* $\sqrt{231{,}600\ H}$.

„ 232.—For ventilating pressures, *read* furnace ventilating pressures.

PREFACE TO THE SECOND EDITION.

The Second Edition of "A Practical Treatise on Mine Engineering" is presented to the Public with far greater diffidence than was felt in presenting the first.

The First Edition was an Abstract of a Course of Lectures delivered at the Newcastle-upon-Tyne College of Practical Science in the year 1852, in the preparation of which very little assistance of a practical character, on Mining subjects, was attainable in the English language; a ready excuse for deficiencies was, therefore, at hand; a more ready pardon for them demands a grateful acknowledgment.

Sixteen years ago there were no Mining Institutes; or, perhaps, to speak more exactly, that which was first established was little more than a seed. Now, that they have taken root and flourished in the land, it may be said that the information contained in their volumes supersedes the necessity of this Second Edition; it may, however, it is thought, be fairly replied, that the present Treatise, not being intended to enter in detail into many of the matters treated of in the volumes referred to, will remain, as it was first intended to be, a Practical Book, written for the purpose, not only of instructing the beginner in the art of mining, but of aiding those who are more conversant with it, in the execution of mining work.

It has frequently been the Author's gratification to hear that works have been laid out and executed in accordance with the recommendations contained in his book; and he wishes it to be understood that the instructions contained in it are intended to be such as may be safely followed with proper working results.

This Edition will be found to be substantially similar to the first—that is, similar in object. The changes, however, which have taken place during the last sixteen

years in mining matters, particularly in machinery, and the extended range of observation possessed by the Author during that period, have compelled the entire re-writing, and in some cases the re-construction of the work. As before, the Author has to acknowledge many obligations, both to previous writers and to private friends, for much contained in these editions: he has endeavoured to avoid charges of plagiarism, but is afraid that in some cases the memory of circumstances, and not of their historians, may have laid him open to such. To these he begs to apologise; and all, to thank.

POYNTON, *September 12th*, 1868.

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APPLICATION OF GEOLOGY TO MINING—ALLUVIAL DEPOSITS—CHALK AND GREEN SAND FORMATION—IRONSTONE OF THE GREEN SAND—WEALDEN—OOLITE AND LIAS—OOLITIC COAL—ALUM SHALE—IRONSTONE OF THE CORAL RAG AND LIAS—NEW RED SANDSTONE—COPPER SAND—HÆMATITE—SALT—MAGNESIAN LIMESTONE—LOWER NEW RED SANDSTONE—COAL MEASURES—VARIOUS COAL FIELDS—SOUTH STAFFORDSHIRE COAL FIELD—SOMERSETSHIRE COAL FIELD—NEWCASTLE COAL FIELD—MILLSTONE GRIT—MOUNTAIN LIMESTONE—BERWICK COAL FIELD—LEAD AND COPPER—IRON ORE—OLD RED SANDSTONE—SILURIAN AND CAMBRIAN ROCKS—SLATE—GRANITE—PORCELAIN.

The variation of the prominent rocks of one locality from those of another, we find to be represented on a geological map by a difference of colouring—thus, in Northumberland, Staffordshire, Glamorganshire, &c., we have districts coloured black, containing coal bearing strata; in other parts of Northumberland, in Derbyshire, Somersetshire, &c., we have districts coloured blue, containing mountain limestone; in Cheshire, Warwickshire, &c., we have districts coloured light red, containing new red sandstone; and so on. (See Professor Ramsay's Geological Map of England and Wales.) We must not, however, infer from this, that because in any given locality a particular formation is shown, others are not to be found as well: the contrary, as a general rule, is the case; and the chief points to which it is necessary to attend, are, firstly, the identification of the formation exposed; and, secondly, its relative position to other formations, so that the great mistake, which has sometimes been made, of searching for that which cannot exist, may be avoided. The following are the formations in their order, commencing with the highest: the whole require attention for the reason just given, but those most especially, opposite to which are placed the names of certain minerals which they contain, and with which, in consequence, the mining engineer is brought most immediately into contact (Plate 1):—

		PRODUCTS.
	ALLUVIAL DEPOSITS.	
1	TERTIARY FORMATION.	
2	CRETACEOUS FORMATION.	
	a Chalk, with Flints	*Coal.*
	b Chalk, without Flints	*Coal.*
	c Chalk Marl	
	d Upper Green Sand	
	e Gault	*Coal.*
	f Lower Green Sand	Ironstone.
3	WEALDEN FORMATION.	
	a Weald Clay	*Coal.*
	b Hastings Sand	Ironstone.

		PRODUCTS.
4	OOLITIC FORMATION.	
	a Purbeck Beds	
	b Portland Beds	Building Stone.
	c Kimmeridge Clay	
	d Coral Rag	Ironstone.
	e Oxford Clay and Kelloway Rock	
	f Cornbrash and Forest Marble	
	g Bradford Clay, Great Oolite, and Stonesfield Slate	Building Stone, Coal.
	h Fullers Earth	
	i Inferior Oolite	Coal, Ironstone.
5	LIAS FORMATION.	
	a Upper Lias	Ironstone, Alum, Jet.
	b Lias Marlstone	Ironstone.
	c Lower Lias	*Coal.*
6	TRIAS FORMATION.	
	a Variegated Marls, Saliferous and Gypseous Shales and Sandstones	Salt.
	b Sandstone and Quartzose Conglomerate	Copper, Lead, Cobalt.
7	PERMIAN FORMATION.	
	a Magnesian Limestone	
	b Lower New Red Sandstone	
8	CARBONIFEROUS FORMATION.	
	a Coal Measures	Coal, Ironstone, Building Stone, Lime.
	b Millstone Grit	
	c Mountain Limestone	
9	DEVONIAN FORMATION.	
	a Conglomerate and Old Red Sandstone	
	b Cornstone and Marl	
	c Tilestone	
10	SILURIAN FORMATION.	
	a Upper Ludlow Rock	
	b Aymestry Limestone	
	c Lower Ludlow Rock	
	d Wenlock Limestone	
	e Wenlock Shale	
	f Llandovery Shales and Slates	
	g Caradoc Sandstone	
	h Llandeilo Flags	
11	CAMBRIAN FORMATION,	
	a Slate Rocks of North Wales, Cumberland, Westmorland, &c.	Slate.
12	METAMORPHIC ROCKS.	
	a Clay Slate	
	b Talcose Slate	
	c Mica Slate	
	d Hornblende Slate	
	e Gneiss	
13	VOLCANIC ROCKS.	
	a Basalt, &c.	
14	PLUTONIC ROCKS.	
	a Granite, &c.	

The products printed in Italics are not found in the respective formations in this country. The metallic ores of copper, lead, tin, &c., are found in veins, which traverse the whole of the above formations: they are, however, rarely worth working, except when found below the millstone grit.

Alluvial Deposits (Plate 2).—Beneath the soil, or vegetable earth usually found at and immediately under the surface, we frequently find a deposit of alluvial matter, which consists of various clays, loams, sands, and gravels: the result of either the subsidence of the mud suspended in the waters of rivers which have overflowed their banks, or of the conveyance by such rivers of similar mud, gravel, &c., into their estuaries, or into lakes or inland seas, or of deposits from other floods, of whose character we can only form a conjecture.

As an example of these deposits may be taken that of the valley of the river Team, towards its confluence with the Tyne, as sunk through at Norwood Colliery:—

	FATHS.	FT.	IN.
Soil...	0	1	4
Dark mud, with vegetable matter in abundance...	1	5	8
Loamy blue clay	5	0	0
Loamy clay, with beds of sand from 1 to 3 inches thick ...	4	1	0
Loamy blue clay	0	5	0
Strong blue clay, with large boulders	2	0	2
Sand and gravel with tumblers	2	3	4
Sand	0	0	8
	16	5	2

Soft blue metal (argillaceous shale).

The layer of mud, near the surface, is a deposit from still or sluggish waters: in some parts it slightly borders on peat, and in proof of its recent formation, a piece of oak, that was found at the depth of 10 feet beneath the surface, proved, when cut through, to be perfectly sound. Indeed, as these low grounds are flooded several times in the course of the year, they must receive an augmentation at a rapid rate.

At Prudhoe Main Colliery, in sinking the John Pit, near the Tyne, eight miles west of Newcastle, the surface deposit consisted of

	FATHS.	FT.	IN.
Sand and Gravel	6	5	10

The sand was "quick," and contained a feeder of water of 450 gallons per minute. At the bottom of the sand was a gravel bed of very large rolled stones: in the gravel, several nuts were found, and in the soil at the top of the pit, some pistol bullets, arrow heads, and two curiously formed horse shoes.

Another example may be given of an alluvial deposit, at Shincliffe Colliery, near Durham, in which the base of the alluvium is above the present level of the river Wear.

	FATHS.	FT.	IN.
Soil	0	1	0
Yellow clay	0	1	0
Blue clay	0	1	4
Dark loamy sand	0	3	8
Loamy blue clay	0	1	0
Dark loamy sand	0	1	8
Loamy blue clay	0	1	6
Light loamy damp sand	0	1	0
Strong blue clay	2	2	0
Light loamy dry sand	1	1	0
Fine clay mixed with loamy sand	0	4	0
Light loamy dry sand	0	2	0
Dark brown loamy clay	0	4	0
Fine dry loamy sand	3	5	8
Dry sharp sand	1	5	6
Dry loamy sand	1	1	5
Damp sand...	0	4	0
Sand with water (quick)	0	5	4
Strong blue clay	0	4	6
Strong sandy blue clay	0	0	5
Strong stony blue clay	3	3	7
Sand parting	0	0	6
Strong blue clay	0	3	0
Sand parting	0	0	6
Strong blue clay	2	0	0
Brown leavy clay	1	2	6
Strong brown clay	0	1	9
Dry loam	3	2	2
Dry sand	0	2	0
Damp sand	0	0	6
Strong soily clay with large boulders	1	3	0
	29	5	6

Soft blue metal.

The above description of alluvial beds may be taken as fairly representing those with which, in England, the miner is likely to be brought in contact at present. They are not, however, to be confounded with

1. The Tertiary Formation (Plate 3), of which we have examples in Norfolk, Suffolk, and in the London and Hampshire basins, and which it does not appear necessary to describe more particularly in this place. On the Continent, however, coal mines are sunk through the Tertiary formation, as will be illustrated hereafter.

2. Cretaceous Formation.—*a The Chalk* abounds in the southern and eastern counties of England, and is largely exposed in the cliffs between Flamborough Head

and Weymouth. It consists of nearly pure carbonate of lime, and abounds in organic remains. Chalk is usually soft, but is occasionally found of sufficient hardness to be used for building. Much of the foundation work of the Grimsby dock is constructed with this substance. It is now used largely as a flux in iron-smelting, being substituted for limestone, when it can be procured at a cheaper rate.

The miner of this country has little acquaintance with the chalk, in the search for those substances which he seeks to extract from the bowels of the earth. In the north of France and in Belgium, however, in sinking to the coal measures, the cretaceous formation, in some instances of the thickness of 70 fathoms, requires to be passed through before the coal measures are reached.

The following is a section of the strata bored through at Marchiennes (Nord), between Douai and St. Amand, by M. Degousée, into the coal measures (Guide du Sondeur). The Colliery of Marchiennes has been established subsequently to the execution of the borehole. (Plate 4.)

	FAT.	FT.	IN.	FAT.	FT.	IN.
ALLUVIAL—						
Vegetable mould and yellow clay ...	1	3	3			
Peat	0	3	8			
				2	0	11
TERTIARY—						
Bluish sands	1	2	9			
Green clayey sands	4	4	5			
Grey compact clay	5	3	11			
				11	5	1
CRETACEOUS—						
Chalk.						
White chalk, with flints	17	1	10½			
Grey marly chalk	2	1	1½			
Do. do. with flints	6	3	11			
Green Sand?						
"Dièves" (beds of clay, usually green, sometimes reddish, impermeable to water	29	4	10			
"Tourtia" (gravels and rolled flints) ...	0	2	2			
				56	1	11
				70	1	11

Into Coal Measure shales and sandstones.

f The Lower Green Sand contains ironstone in considerable quantities; and at Seend, in Wiltshire, it has been largely worked. It caps the hill on which the village is situated. The following is a section :—

	FAT.	FT.	IN.
Soil	0	3	0
Iron ore compact	2	0	0
Iron ore, in beds of variable thickness, interstratified with thin layers of sand	2	1	6
Blue clay			

The following is an analysis (Mitchell) :—

Peroxide of iron	57·150
Protoxide of iron	1·800
Oxide of Manganese	0·315
Alumina	1·072
Lime	0·314
Magnesia	0·721
Potash	0·512
Soda	0·384
Phosphoric acid	0·210
Sulphuric acid	traces
Silica	26·830
Water	10·421
Loss	0·268
	100·000
Metallic iron	41·017

The thickness of the iron stone, however, is very variable. On the summit of the hill it is probably from 30 to 40 feet thick, but, where proved of great thickness, it is interstratified with more sand.

The thickness of the Cretaceous Formation may extend to 340 fathoms in the south of England.

			FEET.
2 CRETACEOUS FORMATION	*Upper*	*a* Chalk with flints	1000 in some places.
		b Chalk without flints	
		c Chalk marl, or grey chalk, slightly argillaceous ...	
		d Upper green sand	100, Isle of Wight.
		e Gault ... ... (Lyell)	100, S.E. of Englnd.
	Lower	*f* Lower green sand ... ... (E. Forbes)	843, Isle of Wight.

(Lyell's Elements of Geology, 1865, page 312.)

3. WEALDEN FORMATION.—This formation consists of—

		FEET.
3 WEALDEN FORMATION	*a* Weald clay, blue and brown clay and shale, with thin beds of sand and shelly limestone	600 in some places.
	b Hastings sand, chiefly arenaceous, but with some clays and calcareous grits	740

(Dr. Fitton, Geol. Trans., second series, vol. iv., page 320.)

In Sussex, iron was extensively manufactured from the iron ore of the Wealden formation. In the time of Edward II., the Sheriff of Surrey and Sussex had to provide within his district, for the expedition against Scotland, 3,000 horse shoes and 29,000 nails, which, with the expense of carriage and delivery in London, cost

£14 13s. 10d. One of the earliest notices of the manufacture in Sussex dates in the year 1290, and relates a payment made for the ironwork of the monument of Henry III., in Westminster Abbey, to Master Henry, of Lewes. The first iron cannons cast in England were manufactured at Buxted, in 1543, during the reign of Henry VIII., the production of heavy ordnance giving a great impetus to the trade; and the balustrades round St. Paul's Cathedral, in London, afford us a distinguished specimen of Sussex made iron.

Although in the Tertiary strata we have fossilized wood in large quantities, forming lignites, as at Bovey Tracey, in Devonshire, yet we do not find any coal in England until we come to the Wealden beds.

The sinkings at Bexhill, in Sussex, in search of coal, were, at a great expense, conducted in beds of this formation. It is said that a kind of cannel coal, extending for a quarter of a mile, in beds of from two to ten inches thick, occurs in the banks of a stream in that county. (Outlines of the Geology of England, page 137.)

A bed of impure coal is reported to have been discovered in excavating for a dock at Shoreham, in clay beds cropping out from beneath the South Downs chalk escarpment. (Holdsworth, Extension of English Coalfields, page 93.) But whether this is Wealden coal or not, does not appear.

According to Dr. Mantell, Hanoverian coal fields are situated in deposits of the Wealden period. (Wonders of Geology, page 688.)

Dr. Beck assigns the same period for the coal of Bornholm, in Denmark.

4. Oolitic Formation.—*a Purbeck Beds:* thickness, 277 feet. (Middleton, Monthly Magazine, Dec., 1812.)

Purbeck marble, formerly much used in Gothic churches for columns and monuments, was obtained from nearly the uppermost of these beds. It is largely exhibited in the decoration of the Lady Chapel in Wells Cathedral.

b Portland Beds: thickness, 112 feet. (*Ibid*, Jan., 1813.)

The more Oolitic varieties (principally quarried in the isles of Purbeck and Portland) afford a great part of the stone used for architectural purposes in London and its vicinity.

c Kimmeridge Clay: thickness, 700 feet. (*Ibid.*)

Mr. Middleton assigns upwards of 700 feet as the thickness of this division in the Isle of Purbeck; the late Dr. Buckland only 600 feet. Near Oxford, where the beds thin off, the thickness cannot exceed 100 feet. In the pit at Sunning Well, on the north edge of Bagley Wood, it was 70 feet. (Outlines of Geology, page 178.)

The Kimmeridge clay consists chiefly of bituminous shale; and on the eastern shores of Weymouth Bay, an imperfect stone coal, of about two feet thick, is found interstratified with the bituminous shale and cement beds. (Holdsworth, Extension of English Coalfields, page 93.)

d Coral Rag: thickness, 100 to 150 feet. (Outlines of Geology, page 192.)

In the vicinity of Weymouth, the beds at the junction of the Kimmeridge clay, and the freestones of the coral rag, are very sandy and ferruginous. (Outlines of Geology, page 187.)

These beds are the ironstone of Westbury, in Wiltshire, of which the following is the section :—

	FT.	IN.	FT.	IN.
Soil			2	6
Hard shelly ore...	0	9		
Soft ore...	0	3		
Compact ore	8	0		
Soft ore, with oyster shells	3	0	12	0

When covered by the Kimmeridge clay, and consequently protected from the action of the atmosphere, this ironstone is of a dark bluish green colour, and tolerably compact and hard; in this condition, its constituent parts are, according to the analysis of the late Dr. Thomas Richardson—

Protoxide of iron	44·53
Lime	3·37
Magnesia	trace
Alumina	1·40
Silica, &c.	16·55
Loss by heat	29·77
	95·62
Metallic iron	34·39

When only covered by the soil, as in the section given above, the iron becomes peroxidized, and the colour of the ore is, in consequence, changed to a reddish brown, which a moderate red heat converts into a bright red; it is less compact and much more friable than when in the green state, and its structure becomes purely oolitic.

e Oxford Clay and Kelloway Rock: thickness, from 500 to 700 feet. (Outlines of Geology, page 199.)

f Cornbrash and Forest Marble: thickness from 46 to 90 feet. (*Ibid*, page 202.)

g Bradford Clay; Great Oolite and Stonesfield Slate: thickness, from 156 feet to 246 feet. (*Ibid*, page 202, and Lyell's Elements of Geology, page 402.)

The Great Oolite affords the celebrated Bath freestone, so extensively employed as a building stone in the southern counties of England, and elsewhere.

In the north-east of Yorkshire, there are found an upper and lower series of carbonaceous sandstones and shales, abounding in impressions of plants, divided by a limestone, considered by many geologists to be the representative of the Great Oolite.

A seam of coal occurs nearly at the top of the lower series, which, according to the Rev. George Young, extends about 40 miles in length by about 4 miles in breadth. This author states that the coal is of very variable character, there being sometimes a single seam, sometimes numerous thin seams, and sometimes none at all. In quality, the coal is equally variable, being sometimes slaty, but at others of excellent quality, breaking with a smooth shining cubical fracture. The seams appear thinnest next the sea coast. In the interior they are more considerable, and the greatest thickness is at the Danby pits, where the seam is 17 inches, and the depth from the surface from 15 to 60 yards. (Geological Survey of the Yorkshire Coast, page 118, &c.)

The coal field of Brora, in Sutherlandshire, belongs to the Oolitic period, and probably corresponds with that last-named. From the sections published, it appears there are two seams which are workable, besides some thin beds which are not so. The quality is bituminous, of a cubical fracture, burning to a white ash, but subject to spontaneous combustion, unless separated from the pyrites which abounds in the shale.

The Brora coal pit, in operation when Sir R. Murchison visited it, in 1826, was sunk to the depth of 230 feet, the roof of the coal bed consisting of a compressed assemblage of leaves and stems of plants, passing into shaly coal. It is particularly characterized by a large species of *equisetum,* which also occurs abundantly in the Yorkshire Oolitic coal field. This plant is described by Mr. König, and is thought by that naturalist, as well as by Sir R. Murchison, to have largely contributed towards the formation of the coal. The main seam, which varies from 3 feet 3 inches to 3 feet 8 inches thick, is a pure bituminous coal, sub-divided in the middle by a thin layer of pyritiferous shale, which has at times occasioned the combustion of the whole mass. But for the evidence of the fossil shells and plants, which testify to its geological age, it might readily have been supposed that the coal seam belonged to the true coal era.

Two sections of the borings for coal, at the Brora Colliery, are published. The first is 251, and the other 338 feet deep. The coal field is limited in extent: it rests upon granite, and the strata belonging to the coal formation are in immediate contact with the primitive rock throughout the greater part of their extent. The coal itself may be traced within a few feet or inches of the granite, the intervening matter consisting of shale. Three seams have been worked here: the first is impure and abandoned; the second is three feet thick; and the third is from three to four feet, and of better quality than the others. An engine pit has been sunk, 45 feet below this level, passing through two other and thinner coal seams, and a bed of fine fire clay.

Sir R. Murchison states, that the Sutherland coal differs in no respect from true coal, chemically, but that when powdered it assumes, with all lignites, a red ferruginous tinge, instead of preserving the blackness characteristic of the true coal. It may be considered one of the last links between brown coal and true coal, approaching very nearly in character to jet. (Transactions of the Geological Society, London, vol. ii., new series, 1827.)

The Richmond coal field, of Virginia, and the Burdwan coal, of Hindostan are supposed to approach the period of the formation of the Brora coal. (Taylor, Statistics of Coal, page 345.) For some further speculations upon the Brora coal field, the reader is referred to a paper, by Mr. Robertson, communicated to the Geological Society, and contained in the Quarterly Journal, vol. 3.

The Oolite of the Isle of Mull, contains a lignite bed, which has been partially worked for fuel, apparently corresponding with the Yorkshire and Sutherland coal fields above-named. (Murchison.)

h Fuller's Earth: thickness, 135 feet. (Warner's Bath Guide.)

i Inferior Oolite: thickness, 80 feet. (*Ibid.*)

At the present date, the Inferior Oolite is the highest rock through which shafts have, in this country, been sunk into the true Coal Measures. (Plate 5.)

At Braysdown Colliery, about six miles south-west of Bath, we have—

		FAT.	FT.	IN.	FAT.	FT.	IN.
	Soil ...				0	1	0
Inferior Oolite	Broken stones ...	0	5	0			
	Bastard freestone ...	1	3	0			
	Cockly do. ...	1	3	0			
					3	5	0
Lias Marl.							

And at Paulton—

	FAT.	FT.	IN.
Soil.			
Inferior Oolite—Bastard freestone ...	3	0	0
Lias Marl.			

According to the thicknesses of the Superior formations given above, the Inferior Oolite *might* be 5,793 feet below the top of the chalk, but this would only be the case where each formation should, in that one locality, be found to be of its maximum thickness, a circumstance inconsistent with actual observation. We have already seen, that in Belgium and in the North of France, the entire thickness of the Cretaceous formation is sometimes only 338 feet, and that all of the formations intermediate between it and the coal measures are extinct; and we have also seen that a member of the Oolites (Kimmeridge clay) varies from 700 feet to 70 feet.

Mr. Brown (Transactions of the South Wales Institute of Engineers, vol. 2, page 191) states that the geological position of the Northamptonshire iron ore is in the Inferior Oolite and Marlstone bed, and that the ore frequently reposes upon, or is succeeded by, a very thick deposit of dark blue clay of the Lias. In structure and appearance, it greatly differs from the almost identical formation of the Cleveland stone, being exceedingly ferruginous in appearance when exposed to the action of the atmosphere; whilst the Cleveland stone is of a pale grey colour, more rocky in appearance, and of unbroken structure. The depth, from the surface at which it is

found, varies: in some places, it is found two or three feet deep, and at others, at twenty or twenty-five feet.

The following are analyses of the Duston ores, by Mr. Bernays:—

Peroxide of iron	67·20	58·40	44·00
Sand and silica	11·00	21·60	34·00
Alumina	11·00	5·20	4·52
Water	10·40	12·00	14·08
Unestimated	·40	2·80	3·40
	100·00	100·00	100·00
Metallic iron	46·59	40·50	30·50

5. Lias Formation.—

			FT.
a Upper Lias—Thickness at		Bath	220
	Do.	Paulton	129
	Do.	in Yorkshire	200 (Phillips)
b Lias Marlstone—	Do.	Bath	47½
	Do.	Paulton	19½
	Do.	Yorkshire	150 (Phillips)
c Lower Lias—	Do.	Bath	19½
	Do.	Paulton	15
	Do.	in Yorkshire	500 (Phillips)

The following is a detailed section of the Lias sunk through at Paulton (Somersetshire).

	FAT.	FT.	IN.	FAT.	FT.	IN.
Upper Lias Marls				20	0	0
Lias Marlstone—						
Grey and blue lias rock	1	0	0			
Sunbed, or corngrit, in three beds, slightly oolitic	0	1	6			
White lias	2	0	0			
				3	1	6
Lower Lias Marls—						
Blue marl	1	0	0			
Clay stone, forming concretional and rubbly masses	0	3	0			
Black marl (excellent for manure) ...	1	0	0			
				2	3	0
				25	4	6

New Red Sandstone.

In the shales of the Upper Lias are found those worked at Boulby, and other places on the Yorkshire coast, for alum. The process of making this salt is shortly as follows:—the shale is calcined by means of a slow smothered fire; it is then lixiviated; the water concentrated by evaporation; then mixed with muriate of potash, when

crystals of alum and sulphate of iron form together. (Thompson's Inorganic Chemistry, vol. 2, page 757.)

The Lias formation has acquired great importance of latter years, from its containing very large ironstone deposits. These are especially prominent in Cleveland; but they are not confined to the Lias of that localty, ironstone of more or less richness being found to exist in most, if not all, of the Lias districts.

Section of the strata under Eston Nab, near Middlesbrough. (Marley, Transactions of the North of England Institute of Mining Engineers, vol. 5, page 189.)

	FAT.	FT.	IN.	FAT.	FT.	IN.
Soil and other strata unproved	8	2	0			
Freestone	10	0	0			
Shivery post, patches of jet and fireclay ...	9	0	0			
(The freestone and shivery post belong to the Inferior Oolite, and the patches of jet and fireclay form the upper part of the Upper Lias.) Approximated ...				27	2	0
Top Seam Ironstone—						
Nodular ironstone	0	0	1			
Shale	0	2	3½			
Nodular ironstone	0	0	3			
Shale	0	0	7			
Nodular ironstone	0	0	0½			
Shale	0	0	10			
Nodular ironstone	0	0	1			
Shale	0	0	6			
Nodular ironstone	0	0	1			
Shale	0	0	6			
Ironstone band, varies	0	0	9			
				1	0	0
Lias shale, including jet rock at bottom (approximated)				35	0	0
Ironstone band	0	0	2			
Shale	0	2	5			
Ironstone band	0	0	2			
Shale, mixed with nodules of ironstone ...	0	1	10			
Ironstone band	0	0	3			
Shale	0	1	0			
Shale, inclining in some places to a fireclay nature	0	4	2			
				1	4	0
Cleveland Main Thick Stratified Bed, or Seam of Ironstone—						
Top block left as roof	0	0	11			
Parting, regular at outcrop, but not so after	0	0	0			
Second block left as roof near outcrop ...	0	2	3			
				0	3	2
Carried forward				65	3	2

	Fat.	Ft.	In.	Fat.	Ft.	In.
Brought forward ...				65	3	2
Main parting (a good one at outcrop, but lost further in)	0	0	0			
Main block of ironstone, uniform	2	0	0			
Parting, lost after leaving outcrop	0	0	0			
Bottom block, varies...	0	1	10			
				2	1	10
Shale	1	1	0			
Ironstone band, called two-feet band ...	0	1	8			
Shale	1	0	0			
Ironstone band	0	0	10			
				2	3	6
Blue shale	...	...	...	6	0	0
Various beds of grey post and metal stone, &c. (approximate); Lias Marlstone ? ...	...	...	...	15	3	6
				92	0	0

Section of the strata at Port Mulgrave—

	Fat.	Ft.	In.	Fat.	Ft.	In.
Soil	...	...	...	0	3	0
Clay	...	...	...	2	2	0
Freestone, Inferior Oolite	...	...	...	4	2	0
Fireclay	...	...	...	0	4	6
Freestone shale	...	...	...	0	5	5
Blue shale	...	...	...	0	0	10
Top Seam of Ironstone—						
Ironstone dogger	0	0	3			
Blue shale	0	2	2			
Top block ironstone	0	1	6			
Parting	0	0	0			
Bottom block ironstone	0	2	10			
				1	0	9
Cement dogger	...	...	...	1	4	0
Alum shale	...	...	...	26	4	0
Jet dogger	...	...	...	0	1	0
Jet rock	...	...	...	3	1	0
Blue shale	...	...	...	10	1	0
Ironstone dogger	...	...	...	0	0	6
Blue shale	...	...	...	0	3	4
Main Seam of Ironstone—						
Ironstone	0	3	0			
Blue shale	0	0	7			
Ironstone	0	2	10			
				1	0	5
Blue shale	...	...	...	0	1	0
Carried forward				53	4	9

	FAT.	FT.	IN.	FAT.	FT.	IN.
Brought forward ...				53	4	9
Ironstone	0	0	3			
Blue shale	0	0	3			
Ironstone	0	0	3½			
Blue shale	0	1	6			
Ironstone	0	0	5½			
Blue shale	0	0	5½			
Ironstone	0	0	4½			
Blue shale	0	0	2½			
Ironstone	0	0	6			
Blue shale	0	0	5½			
Ironstone	0	0	7			
Blue shale	0	0	3½			
Ironstone	0	0	3½			
Blue shale	0	0	4			
Ironstone	0	0	5½			
				1	0	8½
Blue shale				0	3	0
Ironstone				0	1	6
Blue shale				1	3	9
Ironstone				0	0	10
Blue shale				2	3	0
Ironstone				0	2	0
Blue shale				5	3	0
				65	4	6½

Analyses of Main Band of ironstone from Eston Nab. (Crowder, Edinburgh New Philosophical Journal, new series, vol. v., January, 1857.)

	A	B	C	D	E	F	G
Silica	10·90	11·95	6·00	7·65	7·55	19·90	19·50
Peroxide of iron ...	3·55	6·73	3·95	1·20	...	1·55	2·45
Protoxide of iron ..	39·01	39·05	40·85	43·35	41·22	39·50	24·93
Alumina	10·62	13·83	12·66	9·88	14·28	17·87	12·72
Lime	1·70	2·52	trace	0·58	trace	1·56	8·56
Magnesia	3·19	2·72	3·19	5·35	5·48	2·31	1·80
Sulphur	trace	trace	trace	0·09	trace	0·13	0·10
Phosphoric acid ...	2·08	1·02	2·49	3·87	1·02	2·50	1·88
Carbonic acid ...	25·26	16·38	26·16	22·96	25·32	5·54	41·54
Water	3·69	5·80	4·70	5·07	5·13	9·14	9·07
	100·00	100·00	100·00	100·00	100·00	100·00	100·00
Metallic Iron ...	32·83	35·10	34·54	34·54	32·06	28·73	21·10

EXTERNAL CHARACTERS OF THE STONE.

A Cinnamon coloured stone, made up of Oolitic grains.
B and C blue green stone, full of Oolitic grains.
D The same, but dark blue green colour.
E The same, but still darker colour.
F Hard compact stone, olive green colour; no fossils.
G Dirty green colour; highly fossiliferous.

6. Trias Formation.—*a Variegated Marls, Saliferous and Gypseous Shales, and Sandstones (Keuper):* thickness, in Lancashire and Cheshire, from 1,000 to 1,500 feet (Lyell).

b Sandstone and Quartzose Conglomerate (Bunter): thickness, in Cheshire and Lancashire, 600 feet. *(Ibid.)*

Section at Paulton Colliery—

	FATHS.	FT.	IN.
Red marl and sand	22	0	0
Calcareo-magnesian conglomerate, called "millstone" ...	1	0	0
Total thickness of Trias	23	0	0

In the lower part of the Keuper are found, at Alderley Edge and at Mottram St. Andrew, in Cheshire, sandstones containing about $1\frac{1}{2}$ per cent., on the average, of copper; they also contain galena and cobalt ore in small quantities. (Memoirs of Geological Survey, Geology of Country round Stockport, &c., by Messrs. Hull and Green, page 39; also, Transactions of South Wales Institute of Engineers, vol. iii., page 44.)

In the lower portion of the Trias, at Llantrissant, in Glamorganshire, at Clifton, near Bristol, and elsewhere, are found considerable deposits of hæmatitic iron ore, which, at the first-named place, is extensively worked. The hæmatite seems to have been most freely deposited in places where the Trias and Carboniferous Limestone are in juxtaposition.

The following analyses are that of Llantrissant ore, by Mr. W. Ratcliffe, (Iron Ores of Great Britain, page 218;) and that of Clifton ore, by Mr. John Mitchell:—

	LLANTRISSANT.	CLIFTON.
Sesquioxide of iron	70·572	...
Peroxide of iron	...	55·027
Protoxide of iron	...	0·921
Oxide of manganese	0·522	0·584
Silica	18·362	40·511
Alumina	1·572	0·352
Lime	3·562	trace.
Magnesia	1·311	0·912
Potash	0·317	0·214
Soda	..	0·301
Sulphuric acid	0·451	0·110
Phosphoric acid	0·132	0·372
Carbonic acid	1·716	...
Water and loss	0·660	0·695
	99·177	100·000
Metallic iron	48·934	44·75

In Cheshire, in Worcestershire, and in Yorkshire, large deposits of salt are found in the Keuper. At Wilton, near Northwich, the following is a section of the strata sunk through to the second bed of rock salt. (Holland, Geological Transactions, vol. i., page 62.)

	FATHS.	FT.	IN.
1. Calcareous marl	2	3	0
2. Indurated red clay	0	4	6
3. Indurated blue clay and sand	1	1	0
4. Argillaceous marl	0	1	0
5. Indurated blue clay	0	1	0
6. Red clay, with sulphate of lime (gypsum) irregularly intersecting it	0	4	0
7. Indurated brown clay, with grains of sulphate of lime interspersed	0	4	0
8. Indurated brown clay, with sulphate of lime crystallized in irregular masses and in large proportion	2	0	0
9. Indurated blue clay, laminated with sulphate of lime ...	0	4	6
10. Argillaceous marl	0	4	0
11. Indurated brown clay, laminated with sulphate of lime ...	0	3	0
12. Indurated blue clay, with laminæ of sulphate of lime ...	0	3	0
13. Indurated red and blue clay	2	0	0
14. Indurated brown clay, with sand and sulphate of lime irregularly interspersed. The fresh water (360 gallons per minute), finds its way through the holes in this stratum, and has its level at 16 yards from the surface	2	1	0
15. Argillaceous marl	0	5	0
16. Indurated blue clay, with sand and grains of sulphate of lime	0	3	9
17. Indurated brown clay, with a little sulphate of lime ...	2	3	0
18. Indurated blue clay, with grains of sulphate of lime ...	0	1	6
19. Indurated brown clay, with sulphate of lime	1	1	0
20. The first bed of rock salt	12	3	0
21. Layers of indurated clay, with veins of rock salt running through them	5	1	6
22. The second bed of rock salt (not sunk through)	17	4	6
Total depth	55	3	3

A further sinking at Marston, to the north of Northwich, by Mr. Nieuman (where the second bed was proved to be of the thickness of 96 feet), shows the continuation downward of the saliferous marls below it.

	FATHS.	FT.	IN.
From surface to highest bed	21	1	0
First bed	14	1	0
Stone	5	0	0
Second bed (average thickness)	17	4	0
Carried forward	58	0	0

	FATHS.	FT.	IN.
Brought forward	58	0	0
1. Compact blue and brown laminated stone	0	5	8
2. Red salt, with veins of clay	1	0	7
3. Pale red salt	0	3	4
4. Compact laminated brown stone, with thin laminæ of salt ...	2	1	9
5. Pale red salt	1	0	0
6. Compact laminated brown and blue stone, traversed with thin veins of salt	1	1	6
7. Lowest bed of salt, variable in colour, from white to red, with a slight mixture of blue clay	1	5	6
8. Compact laminated brown and blue stone	12	5	0
9. Hard light blue stone, with splintery fracture, with small detached crystals of salt	1	3	0
10. Compact heavy laminated stone, brown and blue, with small portions of salt between the laminæ (bored into) ...	1	5	0
Total thickness of saliferous beds proved near Northwich	83	1	4

Mr. Ormerod (Quarterly Journal of Geological Society, vol. iv., page 288), considers that the brine pits and borings at Middlewich underlie the Northwich beds, the section of which has been given above; and adding their depth, viz., 51 fathoms 3 feet to the above, gives a total explored thickness of the saliferous marls or upper division of the Keuper, as being 134 fathoms 4 feet 4 inches—

Say	808 feet.
Mr. Ormerod estimates the thickness of the lower division of the Keuper or water stones, at	400 feet and upwards.
And that of the Bunter sandstone, at	600 do.
Thickness of Trias in Cheshire, exclusive of any portion of saliferous marl below the thickness explored at Middlewich	1,808 feet and upwards.

Mr. Hull (Geology of the Country around Altrincham, pages 2–3), estimates the thickness of the Water stones and Bunter, at 1,550 feet in Cheshire; and (Geology of Country around Prescot, pages 14 and 15), at from 1,750 to 2,000 feet in Lancashire; and adding these to the explored thickness of the saliferous marls, we should have the thickness of the Trias at Northwich in Cheshire, 2,358 feet, and at Prescot in Lancashire, from 2,558 feet to 2,808 feet. This estimate for Cheshire, it will be observed, is 550 feet higher than that of Mr. Ormerod.

In contrast with these enormous thicknesses, it may be mentioned, that at Mells, near Frome, in Somersetshire, the coal shaft, commenced in the Inferior Oolite, passes through a few feet of Lias into the Coal Measures, the Trias and Permian Formations being altogether absent.

The following is a section of the saliferous and gypseous shales and marls, which have been proved by boring at Middlesbrough. (Marley, Transactions of the North of England Institute of Mining Engineers, vol. xiii., page 19.)

	FATHS.	FT.	IN.
Alluvium—			
1. Dry slime or river mud	1	2	0
2. Sand, with water	1	4	0
3. Hard clay (dry)	1	4	0
4. Red sand, with a little water	0	1	0
5. Loamy sand, with a little water	0	3	0
6. Hard clay (dry)	2	3	0
Trias—(Keuper.)			
7. Rock, mixed with clay and water	1	5	0
8. Rock, mixed with clay (dry)	0	1	0
9. Rock, mixed with gypsum (dry)	1	0	0
10. Gypsum, with water	0	2	0
11. Red sandstone, with small veins of gypsum and water	9	1	0
12. Gypsum rock (dry)	1	0	0
13. Brown shale, with water	0	1	0
14. Red Sandstone	0	4	0
15. Do., with small veins of gypsum and water	2	0	0
16. Blue post stone, with water at bottom	0	3	0
17. Red sandstone, with water	3	1	0
18. Red sandstone	72	5	4
19. Red and white sandstone	0	1	6
20. Red sandstone	35	5	7
21. Do., and clay	0	1	0
22. Red sandstone	8	4	3
23. Do., and clay	1	3	0
24. Red sandstone	11	0	5
25. Strong clay	0	2	9
26. Red sandstone and clay	0	1	6
27. Red sandstone	4	3	5
28. Red sandstone and clay	1	3	0
29. Red sandstone, with a vein of blue rock at 167 fathoms 3 feet	8	1	4
30. Red and blue sandstone	0	1	5
31. Red sandstone	1	0	0
32. Red sandstone and thin veins of gypsum	6	5	1
33. Red sandstone, blue clay, and gypsum	0	1	2
34. Red sandstone, with veins of gypsum	14	3	3
35. Gypsum	0	3	2
36. White stone	0	0	8
37. Limestone	0	2	8
38. Blue rock	0	0	2
39. Blue clay	0	0	2
Carried forward	197	1	10

				FATHS.	FT.	IN.
Brought forward				197	1	10
40. Hard blue and red rock				0	0	10
41. White stone				0	2	7
42. Dark red rock				0	1	2
43. Dark red rock, rather salt				1	0	7
	FATHS.	FT.	IN.			
44. Salt rock, rather dark	2	0	7			
Do., very dark	0	4	1			
Do., very light	0	3	6			
Do., rather dark	4	3	4			
Do., very light	7	1	6			
Do., rather light	1	3	0			
				16	4	0
45. Limestone				0	1	0
46. Conglomerate. This rock resembles limestone, and contains a great quantity of salt				1	0	4
Total depth				217	0	4

If beneath this exist the Water stones and Bunter sandstone, as in Cheshire and Lancashire, the total thickness of the Trias may amount to upwards of 2,000 feet, and possibly reach 3,000 feet.*

The following is the section of the Trias at the Radstock Tyning Pit, about seven miles south-west of Bath :—

Lias—

Trias Formation—

	FATHS.	FT.	IN.
1. Red marl	7	1	0
2. White marl stone	0	2	0
3. Red marl	1	0	0
4. White marl stone	0	2	4
5. Red marl	0	5	0
6. White marl stone	0	1	8
7. Red marl	2	5	0
8. White marl stone	0	5	3
9. Red marl, water 700 gallons per minute	12	3	5
10. Hard reddish grey sandstone	0	1	4
11. Red marl	1	2	0
12. Red conglomerate, very hard	3	1	0
Total thickness	31	0	0

Coal Measures.

* "This Red Sandstone formation is very abundant in Yorkshire, and beds of Gypsum have been proved by boring in the north-east part of that county; and it is by no means improbable that beds of Rock Salt may be found in the same locality, although no brine springs have, as yet, been discovered in the district." (First Edition, page 13.)

A large quantity of water was met with in passing through the Trias: it was not salt: the water was tubbed back with metal tubbing, the foundation of which was laid near the top of and in the Red Conglomerate, which was perfectly dry and impervious to water.

The most easterly collieries of the Midland Counties, viz.:—Shire Oak, near Worksop, and Annesley, near Mansfield, pass through the lower portion of the Trias, the former having 7 fathoms 4 feet 6 inches, and the latter 17 fathoms, of Trias resting upon the top of the Permian Formation.

7. Permian Formation.—

	DURHAM.	NOTTINGHAM.	SOMERSET.
a Magnesian Limestone	600 feet.	114 feet av.	Trace.
b Lower New Red Sandstone	75 feet av.	Absent?	Trace.

The Permian Formation (Plate 6), appears to be chiefly developed in the eastern part of England as a Magnesian Limestone, the maximum thickness of which is attained in the County of Durham. In the north-west of England, the Permian formation is much thicker, being in some places not less than 1,500 feet; but here it consists almost entirely of the lower New Red Sandstone. The entire formation becomes thinner towards the southern counties.

a Magnesian Limestone.

The Magnesian Limestone of Durham consists in its upper part of a soft marl, containing hollow cavities lined with crystals of carbonate of lime. As we descend, it becomes harder and abounds in nodules, which vary in colour from white to a brick red, and consist of sulphate of barytes, or heavy spar, compact and uncrystallized. The colour of the limestone varies from a pale yellowish brown to brown, and in the lower beds assumes a bluish grey colour: some of the beds are very hard and difficult to sink through, and, in general, much water is met with in putting a shaft through this rock. The water is of excellent quality, and is pumped up for the supply of the towns of Sunderland and South Shields.

The escarpment of the Magnesian Limestone may be seen at Boldon, Houghton-le-Spring, Coxhoe, &c., where it resembles a series of capes or headlands, the flat country into which they project having, when covered by the thin mist of early morning, the appearance of a sea. In this respect, the escarpments of the chalk as seen in Wiltshire and elsewhere, and of the Magnesian Limestone, strongly resemble each other.

The structure of this rock varies considerably: in some places, as at Marsden, near South Shields, it is found soft and lamellar, and slightly flexible. When in this form it can be obtained in plates of a quarter of an inch in thickness, and two or three square feet in area. It is most flexible when newly quarried, and becomes more brittle as it dries.

Another form of Magnesian Limestone is nodular, consisting of an aggregation of balls, hard and radiated or concentric; dark brown, and capable of receiving a fine polish, bearing a considerable resemblance to the limestone of the Rock of Gibraltar. These concretions vary in size from that of a pistol bullet to that of a man's head.

Another form of the Limestone is tabular, dividing with a very smooth cleavage into small flags of the thickness of a quarter of an inch. When of this form it is frequently dendritic and also hard.

At the bottom of the Magnesian Limestone is a calcareous shale bed of one or two feet in thickness, which abounds in remains of fish, and is locally called the "Fish Bed."

Plate 7, fig. 1, is the representation of a fish obtained in sinking the colliery at Shotton, in the east part of the Durham coal-field; and fig. 2 was found in a quarry at Thickley, near the (as at present supposed) south-west boundary of the same coal-field.

The following analyses of Magnesian Limestone, made at the Washington Laboratory, Durham, have been kindly furnished to me by Mr. I. Lowthian Bell:—

	Cassop.	Castle Eden.	West Garmondsway.	East Hetton.
Insoluble in hydrochloric acid, peroxide of iron, silica, and alumina	1·0	0·5	3·5	4·0
Carbonate of lime	57·1	54·4	52·6	62·5
Carbonate of magnesia ...	40·8	42·4	38·8	32·5
Water	0·8	2·7	5·1	1·0
	99·7	100·0	100·0	100·0

In an accompanying letter, Mr. Bell says—"You are probably aware that great variations occur in the composition of this rock, even in the same locality: in many instances the carbonate of magnesia does not exceed from one to five per cent. The stratum at Fulwell, Raisby, near Ferryhill, and partially at Cassop, contains so little carbonate of magnesia as to be serviceable in the iron furnaces, but these instances are rare."

The following is an analysis of the Magnesian Limestone of Raisby Hill, already referred to, and is taken from a report, by Mr. Bell, on the Manufacture of Iron, &c. (British Association Report, 1863, page 742):—

Insoluble in hydrochloric acid	0·95
Peroxide of iron and alumina	0·40
Lime	54·62
Magnesia	0·43
Carbonic acid	43·42
	99·82

The old plan of making carbonate of magnesia, by precipitating the magnesia by the addition of carbonate of soda to the mother liquor of the salt pans, when salt was made from sea water, has been largely superseded by the elegant process of the late Mr. H. L. Pattinson, which consists in submitting calcined magnesian limestone to the action of carbonic acid and water, under pressure. The magnesia dissolves out as bi-carbonate of magnesia, from which the neutral carbonate of magnesia is precipitated by the application of heat. (Dr. T. Richardson, British Association Report, 1863, page 711.)

b Lower New Red Sandstone.

The Lower New Red Sandstone consists of a sandstone usually of a soft and friable nature. It is of very variable thickness, being at Haswell, near Durham, in one place, upwards of 120 feet thick, and in another, 700 yards distant, existing as a mere scare or parting. This sandstone is sometimes so disintegrated in condition that it falls like ordinary sand; and when in this condition, it contains a large quantity of water, it is most difficult and expensive to sink through.

At the Murton Colliery, in Durham, this sand was passed through at the depth of 80 fathoms 3 feet 9 inches. The quantity of water pumped, per minute, was 9,306 gallons. The total horse-power employed was 1,584 (nominal). The steam was supplied by 39 boilers, and the consumption of coal was 2,650 tons per fortnight. (Potter, North of England Institute of Mining Engineers, vol. v.)

The following is the section of the Permian Formation, as sunk through at the Murton Colliery:—

	FATHS.	FT.	IN.	FATHS.	FT.	IN.
ALLUVIAL: soil, gravel, clay, &c.				6	3	0
PERMIAN FORMATION—						
Magnesian Limestone.						
Jointy limestone	2	0	0			
Marly limestone	2	3	0			
Craggy limestone	1	1	0			
Marly limestone	16	4	0			
Do., soft	31	1	0			
Brown limestone, strong	3	4	6			
Do., mixed with blue	7	2	8			
Blue limestone, mixed with brown balls ...	1	1	0			
White limestone, mixed with brown ...	3	3	11			
Blue shale (Fish bed)	0	2	0			
Lower New Red Sandstone.						
Sand, with much water	4	3	8			
				74	2	9
Depth to bottom of Permian Formation				80	5	9

At Shire Oak Colliery, near Worksop, the pit passed through the Permian Formation, after having intersected the lower part of the Trias: the following are the details:—

	FATHS.	FT.	IN.	FATHS.	FT.	IN.
ALLUVIAL: soil and sand				1	0	8
TRIAS FORMATION—						
Rocky red sandstone	0	4	0			
Light red rock	0	3	0			
Red marl	0	3	0			
Red rock	1	0	0			
Red marl	1	4	11			
Light sandstone	0	1	6			
Red marl	0	3	6			
Red sandstone	0	3	5			
Red marl	0	3	10			
Light sandstone	0	2	9			
Red marl	0	1	2			
Light sandstone	0	3	6			
				7	4	7
PERMIAN—						
Magnesian Limestone.						
Magnesian limestone	6	4	3			
Light blue close stone	0	5	0			
Dark blue limestone	7	1	8			
Limestone bands (6 to 12 inches), with bands of blue metal	3	1	0			
				17	5	11
Depth to bottom of Permian Formation				26	5	2

There is a very good section, illustrative of the position of the Magnesian Limestone and Lower New Red Sandstone, in the cliff beneath the Priory at Tynemouth, and also near the railway station at Ferryhill; and an excellent opportunity of comparing them in their most northern, and in their most southern English exposure, is afforded by the above, and the sections exposed between Nottingham and Greasley.

Beneath the Lower New Red Sandstone are found, both in the counties of Durham and Somerset, several feet in thickness, of red and purple coloured shales and sandstones which, at the time of the publication of the first edition of this work, were considered as a portion of the Permian formation. The fact, however, of their being found conformable with the coal measures beneath, leads to the conclusion that they are merely a portion of these measures coloured, most probably, by infiltration during the deposition of the formation above. Where, as in Durham, the coal measures are little inclined, the coloured strata lying under the Lower New Red Sandstone, might easily be considered as conformable with it; but in Somersetshire, where the coal measures have a steep inclination, the correct conclusion is easily arrived at.

8. Carboniferous Formation.—

a Coal Measures.

b Millstone Grit.

c Mountain Limestone.

The Coal Measures consist of sandstones and shales, with a few beds of limestone among their upper strata, and a general distribution throughout of beds of true coal. Their thickness varies considerably, owing, most probably, to denudation. It may, in fact, be pretty generally assumed, that in most cases denudation has been the cause of the thinness of any formation as compared with its thicker condition in other localities; and that to the same cause may be attributed the not unfrequent absence of entire formations, which the presence of a geologically superior one would lead us to infer as existing beneath. The exceptions to this general assumption are those cases in which, owing to faults or other disturbances, differences of surface level have been occasioned, prior to the deposition of the upper formation. The Coal Measures then, like other formations, may be of any thickness, up to their greatest limit, which near Bettingen, north of Saar-Louis, is, according to Mr. Von Decken, 20,000 feet; or as shown above, they may be altogether extinct, as on the Mendip Hills, where the Red Conglomerate lies upon the Mountain Limestone. As further illustrations of denudation, on a great scale, may be mentioned the denudation of the Carboniferous Limestone and Old Red Sandstone at Dudley, in Worcestershire, where the Coal Measures lie upon the Silurian Formation: the denudation of the entire Carboniferous Formation near Pill, on the Avon (Somersetshire), where the horizontal beds of the Trias lie upon the inclined edges or outcrops of the Old Red Sandstone: the denudation of the Lias, Trias, Coal Measures, and Millstone Grit, which may be observed by the side of the turnpike road between Wells and Frome, where the Inferior Oolite rests upon the Carboniferous Limestone. Wherever, then, any formation superior to the Carboniferous or any other Formation is found, and where there is no proof to the contrary, the Carboniferous, or any other Formation, *may be found lying immediately under such Superior Formation*, and it may be of any thickness up to its maximum, according to the greater or less amount of previous denudation. (Plates 2, 4, 5, and 6.)

Plates 8, 9, 11, 12, and 13, are sections of coal-fields, and show clearly the relative position of the Coal Measures, with regard to the other Formations, to be (subject to denudation), universal.

Plate 8 (fig. 1), is a section of part of the coal-field of Belgium. According to Mr. Dunn's account of this coal-field, published in his view of the coal trade, it is computed that a sinking of 900 fathoms would be required to command the lowest beds in the Mons district. The western part of this coal-field, and its extension into the Pas de Calais, is overlaid by the cretaceous formation, varying according to the sinkings, from 20 to 140 yards in thickness (see Plate 4), and giving out water; but the coal stratification is remarkably free from water, and generally composed of

argillaceous strata. At Grand Hornu Colliery, the chalk is 70 yards in thickness. In the vicinity of Mons, we learn from the same authority, that there are known to exist 114 seams of coal, but further to the west, that there are no fewer than 131 workable seams of coal:—the descending order in the Mons basin is as follows:—49 seams of "Flenu" coal. This is a bright coal, not readily reduced to small; very easy of ignition; burns with a long and bright flame, and is the best coal for steam purposes. 29 seams of "Hard" coal:—this is a bituminous, caking coal, giving a fine coke; it is used in foundries and blast furnaces, and contains very little pyrites. 23 seams of "Charbon de fine forge:" quality not pyritous; yielding from 65 to 68 per cent. of good coke: these seams are not all workable, and in quality are considered inferior for forge purposes to the coal of St. Étienne, in France. 13 seams of "dry" coal, good for burning bricks and lime. 114 beds in all, which, in general, vary from 18 inches to 2 feet 9 inches in thickness; but some of them are upwards of 6 feet in thickness.

Plate 8 (fig. 2), represents a section of the Saarbrück coal-field in the Lower Rhine.

Mr. Von Dechen observes that the lowest coal strata known in the county of Duttweiler, near Bettingen, north-eastward from Saar Louis, dip 19,406 feet and 20,656 feet under the level of the sea. These coal measures, therefore, lie as far below the level of the sea as Chimborazo rises above it, at a depth where, according to Baron Humboldt (Cosmos), the temperature of the earth must be 435° Fahrenheit. The north-east part of this basin has been crossed and upheaved, in many points, by Trap Rocks, and contains only thin beds of coal of poor quality, but towards the neighbourhood of the Saar, the formation is richer and more developed.

Plate 9 (fig. 1), is a section of the St. Étienne coal-field.

The basin of St. Étienne consists, in its complete state, of three series of seams of coal, separated from each other by masses of strata, barren of coal.

The upper series, that of Aveize, consists of eight seams of coal, varying in thickness from 5 feet to 20 feet: the united thickness being 102 feet, lying in strata of rocks and shales of the thickness of about 165 fathoms. This coal is suitable for the manufacture of coke.

Beneath this series, from 55 to 110 fathoms, lies the second series, called that of Treuil, which consists also of eight beds of coal, varying in thickness from 1 foot 8 inches to 20 feet: the united thickness being 45 feet, lying in strata of rocks and shales of the thickness of about 33 fathoms. These seams vary in quality from inferior to good second class coal, some of it burning to a red ash.

The lowest series of the St. Étienne basin is separated from that of Treuil, by a great thickness of barren rocks, probably more than 100 fathoms, as has been proved by the deepening of the pumping shaft at Treuil.

This series, which is called that of Méons and la Chazotte, consists of seven beds, varying in thickness from 1 foot 8 inches to 13 feet: the united thickness being 48 feet.

This lowest series is divided into the sub series of Méons and la Chazotte—the former consisting of the four upper beds, the third of which is remarkable for the superiority of its coke; and the latter, of the three lower beds (separated by a considerable thickness of barren rock from the upper), of which the quality is somewhat inferior.

It is believed that the coal-field of St. Étienne overlies (although, by the intervention of upwards of 200 fathoms of barren strata), the coal-field of Rive de Gier, a mass of coal-bearing strata of 75 fathoms in thickness, containing several seams of coal of minor thickness and inferior quality, and one called "la Grande Masse," or "la Maréchale," which varies in thickness, sometimes, as at la Peronnière, attaining that of 60 feet. If this supposition be correct, we have the thickness of the Coal Measures of the Loire basin as follows:—

	FATHS.	FT.	IN.
Coal of Aveize series	15	3	0
Associated strata	165	0	0
Barren strata (average)	82	3	0
Coal of Treuil series	7	3	0
Associated strata	33	0	0
Barren strata (at least)	100	0	0
Coal of Méons and la Chazotte series	8	0	0
Associated strata (?)	75	0	0
Barren strata (at least)	200	0	0
Coal of Rive de Gier series	5	0	0
Associated strata	75	0	0
	766	3	0

In the St. Étienne coal basin, therefore, we have in 766½ fathoms of coal measures, 216 feet of coal, equal to 4·7 per cent. of the whole. (The above description of the coal-field of the Loire is chiefly taken from M. Burat's Traité de la Houille.)

Plate 9 (fig. 2), is a section of part of the coal-field of Pennsylvania.

The following observations on this coal-field are extracted from Professor H. D. Rogers' Geology of Pennsylvania, which contains an elaborate description of the magnificent coal-field of that State.

In the descending order the Coal Measures are divided into:—

1. Upper or Newer Coal Shales, or upper barren group, recognised distinctly only in the south-western corner of the State, west of the Monongahela river, and south of the Ohio. There, in the hills of Green County, the total thickness of the group amounts to between 900 and 1,000 feet. It includes four or five thin seams of coal which seldom expand to the thickness of 2 feet. It contains also a number of thin beds of limestone from 2 to 5 feet in thickness, but the chief strata are sandy shales and flaggy micaceous sandstones more or less argillaceous. Some of the shales are calcareous, and when this is so, the overlying soil has more fertility than usually

belongs to the group. No iron ore, in any notable quantity, has been discovered in this part of the formation.

2. Upper or Newer Coal Measures.—This group contains the Waynesburg and Pittsburg beds of coal and several others. That part of the formation which embraces them, measuring it from the top of the Waynesburg seam to the bottom of the Pittsburg coal, has an average thickness of from 200 to 240 feet. It consists, in the more eastern bituminous basins, of argillaceous sandstones, calcareous shales, and thin layers of limestone; but as we pursue it westward, across the Monongahela to Wheeling, the sandstones progressively fade away, the shales become more calcareous, and the limestones greatly increase, until these two latter kinds of rock constitute, on the Ohio river, the principal materials. In this portion of the series we meet with almost no clay iron ore.

3. Older Coal Shales or lower barren group.—Below the upper Coal Measures there lies a group of strata which contains no coal seams of notable dimensions. In the western coal-fields it includes not only several thick strata of soft argillaceous sandstone, but various deposits of red, yellow, and blue calcareous shale or marl, and two or three unimportant beds of argillaceous limestone. This feature grows more and more conspicuous as we advance from the Alleghany Mountains westward into Ohio. The limestones likewise augment in thickness in the same direction, reaching about 30 feet thick at Pittsburg. Their position is near the top of the group. The limits of this group are from the base of the Pittsburg bed to the top of the upper Freeport coal. Very little iron ore occurs in this division of the coal series. Professor Rogers estimates its thickness at 500 feet.

4. Lower Coal Measures.—These consist, in the Anthracite region, of coarse grey micaceous sandstones, with a few massive beds of conglomerate near their lower limits; of grey and bluish argillaceous sandstone; of compact blue shale frequently overlying the coal beds, and also occurring in independent strata; of blue compact shale of rather fine texture, having frequently an irregular and splintery fracture, and containing rootlets of Stigmaria: this is the prevailing floor of the seams of coal; it is a somewhat coarse or siliceous fire-clay; and of beds of Anthracite coal.

The shales and slates of the Anthracite Measures are, on the average, more siliceous than those of the bituminous region: some of these shales are very slightly calcareous, but in all the Anthracite basins there is not one bed of true limestone. Clay iron ore chiefly abounds in the lower portion of the Anthracite Measures. The ore, as a rule, is more siliceous than that of the bituminous measures, and the surrounding shale adheres more firmly to the nodules. Some of the coal seams of the Anthracite district are of extraordinary thickness, being in some districts from 25 to 30 feet thick.

The lower coal measures of the bituminous region are estimated, by the same authority, at 600 feet in thickness in the district of the Alleghany river. The strata

vary from those of the Anthracite region, the sandstones generally being less siliceous and softer and finer in the grain; and the shales, less sandy, of a finer texture, and more argillaceous. Coal and ironstone abound as in the Anthracite region.

5. Seral Conglomerate (Professor Rogers) corresponding to the Millstone Grit.—This consists of grey and whitish quartzose conglomerate, in massive beds, alternating with strata of grey and yellowish sandstone. It underlies both the Anthracite and bituminous coal regions, and contains occasionally regular and even thick beds of coal, identical as to condition with the seams of the generally productive overlying group. Professor Rogers estimates its thickness at 500 feet.

The base of this division of the coal formation is termed by Professor Rogers the near equivalent of the Carboniferous Limestone and its associated strata; and if this be the case, we have, in the usual geological position, the following general section of the coal-field of the Great Appalachian Basin of the United States:—

	FATHS.	FT.	IN.
1. Upper or newer coal shales or upper barren group (average)	158	2	0
2. Upper or newer coal measures	41	4	0
3. Older coal shales or lower barren group	83	2	0
4. Lower coal measures	100	0	0
5. Seral conglomerate (millstone grit)	83	2	0
Total	466	4	0

Beneath which is the equivalent of the Mountain Limestone of England.

The entire extent of the coal formation of the United States has been variously computed as follows:—

133,132 square miles	... ...	(R. C. Taylor, Statistics of Coal.)
196,850 do.	... ...	(Professor Rogers.)
200,266 do.	... ...	(Daddow & Bannan, Coal, Iron, and Oil.)

It is unnecessary, in this place, to enter into any detail, but a very slight examination of the sections accompanying Professor Rogers' splendid book, will at once convince the observer that from these figures very large deductions will have to be made for denudations. In dealing with areas like the above, especially bearing in mind the comparatively few explorations that have been made, and these chiefly at outcrops, a fact which, even standing alone, indicates such denudings, we should be very careful, indeed, not to be too precise in stating as fact, anything the reverse of which, being discovered, would lead to great disappointment. And in the present condition of the coal explorations of the United States, it is probably as unsafe to consider as connected, all the various points of exploration, by continuous coal, as it would have been, in earlier years, to have connected in the same ideal manner the various explored points of other countries. Although, as remarked by Messrs. Daddow & Bannan (Coal, Iron, and Oil, page 83), new developments may be constantly made

of the coal area of the United States, it will be for future generations to put the universal diffusion of coal through it, to the experimentum crucis.

The abundance of coal which is found in Great Britain, coupled with the facilities afforded both by nature and art, for its transportation to places where its application is most desirable, has mainly contributed to the prosperity of this country. Plate 10 shows its distribution, and gives also a general idea of the extent of the individual coal-fields.

Plate 11 (figs. 1, 2, 3, and 4), are sections across the Dudley coal-field in South Staffordshire, which is described in the first Parliamentary Report of the Midland Mining Commission, in 1843.

Mr. Hull (Coal-fields of Great Britain), estimates the South Staffordshire coal-field, at an area of 147 square miles. The general section of the strata, as given by Mr. Jukes (Memoirs of Geological Survey), is as follows:—

	FATHS.	FT.	IN.	FATHS.	FT.	IN.
TRIAS FORMATION.—						
Bunter Sandstone—						
Upper mottled sandstone	83	2	0			
Conglomerate beds	83	2	0			
Lower mottled sandstone	33	2	0			
				200	0	0
PERMIAN FORMATION.—						
Lower Permian, or Lower New Red Sandstone—						
Breccia of felstone, porphyry, and silurian rocks; Red marls, sandstone and calcareous conglomerate, 1,000 to 3,000 feet	...			250	0	0
CARBONIFEROUS FORMATION.—						
Coal Measures (southern district)—						
Red and mottled clays, red and grey sandstone, and gravel beds	133	2	0			
Brooch coal	0	4	0			
Strata, with ironstone	21	4	0			
Thick coal	5	0	0			
Strata, with gubbin ironstone	3	2	0			
Heathen coal	0	4	0			
Strata, with ironstone	18	1	0			
New mine coal	1	2	0			
Strata, with ironstone	2	4	0			
Fire-clay coal	1	1	0			
Strata	5	0	0			
Bottom coal	2	0	0			
Strata, with several courses of ironstone ...	23	2	0			
				218	2	0
SILURIAN FORMATION.—						
Ludlow Rocks, with Aymestry Limestone.						

Towards the centre of the district the Thick, or as it is commonly called, the Ten Yard Coal, lies at the depth of 140 yards from the surface, decreasing in depth towards the north.

From the above section, it appears that in the Dudley district, there are six workable seams of coal of the united thickness of 64 feet, lying within 218 fathoms 2 feet of coal measures, equal to 4·88 per cent. The most important seam, the Thick Coal, has been very extensively worked. The northern portion of the South Staffordshire coal-field extends from Walsall several miles northward, but for the reason just stated (the outcropping of the strata in that direction), the beds are less numerous, and of more limited extent, so that in the neighbourhood of Bilston the Thick Coal itself crops out at the surface. That the productive coal measures extend beneath the overlying New Red Sandstone to an indefinite extent, there is now sufficient proof.

Mr. Matthias Dunn, on the authority of Mr. B. Smith, shows that at West Bromwich the coal seams amount to 43 feet 8 inches, and at Wolverhampton to 67 feet 5 inches in thickness.

Near Dudley, the strata ascertained by the operations there carried on, and described by Dr. Thompson, amounted to 940 feet: of these, 81 feet consisted of coal comprised in 11 seams of various sizes, from 9 inches to 31½ feet: this latter seam (the Thick or Ten Yard Coal), is here 120 yards beneath the surface. It is here divided into 13 layers, separated by very thin partings of slate clay. Every one of these 13 divisions has its name, designation, and peculiarity, so as to be selected for the uses to which it is particularly applicable. The middle series consists of the best quality employed in private houses. The remaining part, amounting to about one-half, is inferior for house purposes, and is only used in the ironworks: this coal does not cake. It makes an agreeable fire, burning to a white ash, like wood, and does not require to be stirred.

Plate 11 (fig. 5), is a section of part of the Bristol coal-field, which has been described by Messrs. Buckland and Conybeare (Geological Transactions, second series, 1824).

The extent is, probably, not less than 200 square miles or 128,000 acres. In the deepest part of the district through which the section is taken, about a mile east of Midsummer Norton, the thickness of the coal measures cannot be less than 8,000 feet or 1,333⅓ fathoms. They may be divided into the following series:—

	FATHS.	FT.	IN.
CARBONIFEROUS FORMATION.—			
Coal Measures—			
Upper coal shales	140	0	0
Upper coal series, called the Radstock series, containing 7 seams of coal of the united thickness of 11 feet, the seams varying from 12 inches to 2 feet 4 inches of good household quality	60	0	0
Carried forward	200	0	0

Brought forward	200	0	0
Second coal shales, which include a stratum of red and green variegated shale, of the thickness of 25 fathoms	126	0	0
Second coal series, called the Farrington series, containing 6 seams of coal of the united thickness of 12 feet: quality not so good as upper series	50	0	0
Upper Pennant shales	40	0	0
Pennant rock, which consists of thick stratified masses of very fissile sandstone, having mica, decayed felspar, and carbonaceous vegetable fragments abundantly disseminated through it, and varying in colour from greenish grey to dark brick red: it is quarried largely for paving and building ...	100	0	0
Lower Pennant shales: thickness estimated from section taken between Radstock and New Rock Colliery, near Chilcompton	420	0	0
Third coal series, called the New Rock series, containing about 12 seams of coal of the aggregate thickness of 35 feet, of medium quality for house use, but adapted for manufacturing purposes	180	0	0
Fourth series, called the Vobster series, containing 12 or 14 seams of coal, of the aggregate thickness of from 30 to 40 feet, of fine bituminous quality: well adapted for coking and smiths' use	130	0	0
Millstone Grit	87	2	0?
Total thickness	1,333	2	0

Plate 11 (fig. 5), shows also the peculiarly contorted character of the seams of coal of the southern portion of the Bristol coal-field. The resemblance between this and the similar contortion of the coal strata in Belgium and the north of France, together with the great similarity that exists between the qualities of the coal of the two districts, points to a relation between the two, which, if established, would lead to the presumption of the existence of a coal-field traversing the southern counties of England, and extending from Bath to Calais.

It was in the Bristol coal-field and its neighbourhood, that the celebrated William Smith, the Father of English geology, first practically proved the correctness of his geological views as to the uniform order of super-position of the rock formations, and demonstrated the soundness of that magnificent system which has since been adopted by men of science over the entire globe.

At the hazard of appearing to dwell too much upon a point which has already been referred to, attention is directed to a comparison between the last paragraph and the sections last given (Plate 11, figs. 1 and 5), and it will be seen how certain geological phenomena are to be interpreted. The particular examination of the circumstances attending these sections will show (1), that, during the entire period of the deposition of the Devonian and the lowest member of the Carboniferous formation,

the surface of country now covered by the South Staffordshire coal-field, was in no condition to receive those deposits; or (2), that, if they were ever deposited, they were denuded prior to the deposition of the upper members of the Carboniferous formation; and from this we learn that, although we may identify any formation, we cannot, by any means, presume that the formation which, geologically, should be subjacent to it, will be found to be so in fact—the not being so is an accident, but it does not invalidate geological truth. A similar examination will also show (1), that, during the, probably, almost entire period of the deposition of the Permian formation, and a large proportion of the period occupied in the formation of the Lias and Trias, the surface of the Bristol coal formation was not in a condition to receive these deposits; or (2), that if they were ever deposited in their full development, they were each, in its turn, subsequently denuded, prior to the deposition of each superior formation; and from this we draw the same conclusion as that arrived at above. There is, therefore, no reason to conclude that from the existence of any formation, any other formation of an earlier date, no matter how remote, may not be immediately subjacent.

I might still further adduce examples of coal-fields, corroborative of the principle laid down, but I do not consider any more necessary. I shall now proceed to give an account of the Newcastle coal-field, which I propose giving more in detail, because a full account of it will give a clear idea of most others, and because of its ample development, little is left to theory or speculation.

The boundary of the Newcastle coal-field, as at present known, is an irregular line, extending from Warkworth by Morpeth, Ponteland, and Shotley Bridge, to Staindrop, and thence east to Aycliffe, and about midway between Castle Eden and Hartlepool: the total area being about 800 square miles, or 512,000 acres.

The general section of this district (Plate 12), consists of the coal measures cropping out to the north, with the inferior measures rising beneath, and dipping to the south into, at present unknown, regions covered by Magnesian Limestone and Lower New Red Sandstone. There is also a western rise and outcrop of the coal measures, thus indicating what would be, more correctly speaking, a south-east dip, and south-west direction, or strike or water-level bearing of the strata. The covering of the whole of the coal-field in the eastern part of Durham, by the Permian Formation, has been already described.

The following is a section of the strata in this district, commencing with the highest and terminating with the lowest, yet proved.

We do not know that, in any one situation, the whole of the strata will correspond to those given below: in fact, the probabilities are otherwise; but in order to approximate to a correct section as nearly as may be, the following series are placed in the order in which they occur—the lower strata as they are proved towards the rise, being placed beneath those upper strata which are proved to the dip of the coal-field.

Monkwearmouth Pit (about a quarter of a mile north of the river Wear), before piercing the coal measures, passed through the following:

ALLUVIAL AND PERMIAN FORMATION.	Faths.	Ft.	In.	Fathoms.	Feet.	Inches.	Fathoms.	Feet.	Inches.
Alluvial.—									
Soil and brown clay, with partings near bottom				11	3	0			
Yellow sand, wet, near bottom				8	0	0			
							19	3	0
Permian.—									
Magnesian Limestone.									
Marl and sand mixed with limestone				4	3	0			
Yellow limestone				16	3	0			
Blue limestone, in plates				10	3	0			
Clay parting				0	0	1½			
Strong grey limestone				1	4	6			
Grey and blue metal	34	4	5½						
				1	2	10			
Lower New Red Sandstone.									
Freestone sand	0	5	0						
				0	5	0			
							35	3	5½
							55	0	5½

No. of seams of coal.	Thickness of seams of coal. Ft.	In.	CARBONIFEROUS FORMATION. COAL MEASURES.	Fathoms.	Feet.	Inches.	Fathoms.	Feet.	Inches.
			Blue and red metal	2	0	0			
1	0	1½	Coal	0	0	1½			
							2	0	1½
			Black, blue, and red metal	4	0	0			
			Strong red and grey freestone	6	0	0			
			Blue metal stone	1	0	0			
2	1	0	Coal, with 2-inch band, near top	0	1	2			
							11	1	2
			Blue metal and post girdles	4	3	0			
3	0	2	Coal, foul and brassy	0	0	2			
							4	3	2
			Strong blue metal and girdles	6	3	7			
4	0	1½	Coal, brassy and not regular	0	0	1½			
							6	3	8½
			Strong blue and grey stone	8	0	0			
			Grey and white post	6	0	0			
5	0	10	Coal good in quality	0	0	10			
							14	0	10
			Blue stone and post girdles	3	0	0			
6	0	2	Coal	0	0	2			
							3	0	2
			Blue stone and grey ironstone girdles	4	5	0			
7	1	2	Coal	0	1	2			
							5	0	2
			Thill and blue metal	0	5	0			
8	0	2	Coal foul	0	0	2			
							0	5	2
	3	9	*Carried forward*	...	...	...	47	2	6

No. of Seams of Coal.	Thickness of Seams of Coal. Ft.	In.	COAL MEASURES.	Fathoms.	Feet.	Inches.	Fathoms.	Feet.	Inches.
	3	9	*Brought forward*	...	...	...	47	2	6
			Blue metal stone	1	1	6			
9	0	10	Coal	0	0	10			
							1	2	4
			Thill and blue metal	0	3	0			
			White post	1	3	0			
			Blue stone and ironstone girdles...	0	4	0			
10	0	10	Coal, foul and mixed with black stone	0	0	10			
							2	4	10
			Black and blue stone and post girdles	8	2	0			
11	2	10	{ Coal ... ... 1ft. 0in. Foul coal... ... ... 0 1½ Coal 1 8½	0	2	10			
							8	4	10
			Thill and black stone, mixed with post	2	3	0			
12	0	6	Coal ... ... 0ft. 6in.						
			Black stone 0 6						
13	0	9	Coal ... ... 0 9 ...	0	1	9			
							2	4	9
			Black stone	0	0	4			
			Strong white post and post girdles	3	4	0			
			Blue stone...	10	0	0			
			White post	11	0	0			
14	1	3	Coal	0	1	3			
							24	5	7
			Thill and white post parting	2	1	9			
15	1	0	Coal	0	1	0			
							2	2	9
			Post and post girdles	9	2	0			
			Coal in north-east part of pit, but not extending above one-eighth round shaft	0	0	11			
			Post and post girdles	4	5	1			
16	2	1	Coal	0	2	1			
							14	4	1
			Shivery post and blue metal below	8	3	11			
17	1	6	Splint coal ... ... 1ft. 6in.						
			Band of stone 1 9						
18	1	4	Coal good 1 4	0	4	7			
							9	2	6
			White post and metal partings	9	3	1			
19	1	6	Coal coarse at top ... ... 1ft. 6in.						
			Soft grey metal band 0 2						
20	2	10	{ Coal strong and good ... ... 2 1 Coal coarse 0 9	0	4	6			
							10	1	7
			Strong white post, coarse, and mixed with pebbles ...	8	3	7			
21	2	3	{ Cannel coal ... ... 0ft. 10in. Coal good 1 5	0	2	3			
							8	5	10
			Grey post and girdles, and grey metal and ironstone girdles	3	3	9			
22	0	5½	Coal coarse, mixed with black stone	0	0	5½			
							3	4	2½
			Black and blue metal and post girdles	[illegible]	4	1			
23	0	2	Coal coarse	0	0	2			
							3	4	3
	23	10½	*Carried forward*	...	...	...	141	2	0½

NO. OF SEAMS OF COAL.	THICKNESS OF SEAMS OF COAL.		COAL MEASURES.	FATHOMS.	FEET.	INCHES.	FATHOMS.	FEET.	INCHES.
	Ft.	*In.*							
	23	10½	*Brought forward*	...	...	...	141	2	0½
			Thill	0	0	10			
			Coal mixed with black stone	0	0	2			
			Thill	0	2	10			
			Strong grey and white post	7	4	11			
24	0	5	Coal	0	0	5			
							8	3	2
			Thill and post	0	0	3			
			Dark grey post, with blue metal and post girdles ...	10	4	8			
25	0	7	Coal	0	0	7			
							10	5	6
			Grey metal and post girdles	2	1	2½			
			Grey and blue metal	2	0	9			
			Grey post and whin girdle	0	2	2			
			Grey metal stone	0	3	9			
			Grey and white post	2	0	5½			
			Metal parting	0	0	1			
			Shivery white post	4	0	8			
			A substance like coal, soft at one side and hard at the other	0	0	11			
			Coal pipe	0	0	2			
			White and grey scamy post	5	4	6			
26	2	0½	Coal	0	2	0½			
							17	4	8½
			Dark post girdles	1	3	8½			
			Grey metal	1	1	6½			
			Black metal	1	2	7			
			White post girdle	0	0	7			
			Grey metal, with post and ironstone girdles	5	0	7			
27	1	10	Coal, with a 3-inch band near the bottom	0	2	1			
							10	5	1
			Thill and grey metal	0	4	3			
			Scamy post	1	2	1			
			Strong white post and partings	2	1	9			
28	2	10¾	Coal (Tyne Yard Seam)	0	2	10¾			
							4	4	11¾
			Thill and grey metal	0	3	10			
			White post and whin	1	4	10			
			Grey metal and post girdles	1	4	3½			
			Grey and black metal	1	1	10½			
			Strong white post	5	3	3½			
			White post and strong partings near the bottom ...	3	3	3½			
			Dark grey metal	0	1	1			
29	5	3	Coal ... ... 5ft. 3in.						
			Band ... ... 0 1½ — Bensham						
30	1	2	Coal ... ... 1 2 — or						
			Band and coal ... 1 9½ — Maudlin Seam.						
31	1	2½	Coal 1 2½						
			... ...	1	3	6½			
							16	2	0½
	39	3¼	Thickness of coal measures to Thill of Bensham seam ...	...	...	...	210	3	6¼

From this section we observe that the quantity of coal contained in the upper 210½ fathoms of the coal measures is equal to 39 feet 3¼ inches, being 3·11 per cent. of the whole.

Hebburn Colliery is situated near the south bank of the river Tyne, and is about 3 miles west of South Shields. It is sunk to the Bensham seam at the "C" pit, and the following is the section of the strata beneath it, as proved by boring :—

No. of seams of coal.	Thickness of seams of coal. Ft.	In.	Coal Measures.	Fathoms.	Feet.	Inches.	Fathoms.	Feet.	Inches.
			Dark metal	0	0	6			
			Grey metal, with hard girdles	1	2	0			
32	1	5	Foul coal	0	1	5	1	3	11
			Dark slaty metal	1	0	0			
			Blue metal, with post girdles	0	5	3			
			Strong white post, mixed with whin	0	1	0			
			Blue metal, with post girdles	0	5	10			
			Strong white post	2	1	8			
			Grey metal and hard girdles	0	3	0			
33	1	9	Coal, with slaty bands	0	1	9	6	0	6
			Blue metal and metal stone, with post girdles	3	2	0			
			Black slaty stone, with foul coal and sulphur (fire-damp)	0	2	6			
			Blue metal	0	1	6			
			Blue metal, with thin girdles	2	2	6			
			Strong white post	4	1	8			
			Grey metal	0	3	4			
			Strong white post	0	2	10			
			Blue metal, inclining to post near top	1	4	10			
			Coal ... ... 2ft. 6in. } Low Main Seam or Hutton Seam.						
			Slaty coal ... 0 3						
34	5	5	Coarse coal ... 0 10						
			Slaty coal ... 0 8						
			Coarse coal ... 1 2						
			... ...	0	5	5	14	2	7
	8	7					22	1	0

From the Bensham seam to the thill of the Low Main seam, is 22 fathoms 1 foot, containing 8 feet 7 inches of coal, or 6·45 per cent.

Wallsend Colliery is situated on the north side of the Tyne, near the river, and nearly opposite to Hebburn. In this colliery the Low Main has been sunk to, and the strata further proved by boring, as follows :—

No. of seams of coal.	Thickness of seams of coal. Ft.	In.	Coal Measures.	Fathoms.	Feet.	Inches.	Fathoms.	Feet.	Inches.
			White thill	0	5	8			
			White post	0	5	7			
			Grey scamy post	0	5	0			
			White post	0	2	0			
			Carried forward	3	0	3			

No. of Seams of Coal.	Thickness of Seams of Coal. Ft.	In.	COAL MEASURES.	Fathoms.	Feet.	Inches.	Fathoms.	Feet.	Inches.
			Brought forward	3	0	3			
			Grey metal	0	3	2			
			White post	0	5	0			
			Grey post	1	3	0			
			White post	2	2	8			
			Blue metal, mixed with post girdles	0	5	0			
			White post	0	4	11			
			Blue metal	0	0	7			
35	0	10	Coal	0	0	10			
							10	1	5
			Grey thill	0	1	6			
			Grey metal	0	1	6			
			Blue metal	0	3	2			
			Grey whin	0	0	6			
			Blue metal	0	2	0			
			White post	0	1	4			
			Blue metal	0	1	0			
			White post	0	0	6			
			Whin	0	0	8			
			White post	0	1	7			
			Blue metal	0	1	1			
			White post	0	2	8			
			Grey whin	0	1	0			
			White post	0	1	0			
			Blue metal, mixed with ironstone girdles	6	0	3			
36	0	5	Coal	0	0	5			
							9	2	2
			Blue metal	0	0	4			
			White post	0	0	7			
			Grey post	1	2	8½			
			Blue metal	0	1	3½			
			Black metal	0	0	10½			
			Grey metal	0	0	4½			
			Blue metal	0	4	7			
37	2	11	Coal ... ... 2ft. 11in.						
			Grey stone ... 0 4						
38	0	7	Coal ... ... 0 7 — Beaumont Seam.						
			Grey stone ... 1 3						
39	1	5	Coal 1 5						
				1	0	6			
							3	5	3
	6	2					23	2	10

From the Low Main to the thill of the Beaumont Seam, is 23 fathoms, 2 feet 10 inches, containing 6 feet 2 inches of coal, or 4·35 per cent.

The Towneley Main Colliery is situated on the south side of the river Tyne, and six miles west of Newcastle. The following is the section of strata below the Beaumont (there called the Towneley) seam, as presented in the Stargate Pit, which is 300 yards north of the downthrow slip to the north, commonly called the 90-Fathom Dyke :—

No. of Seams of Coal.	Thickness of Seams of Coal. Ft.	In.	COAL MEASURES.	Fathoms.	Feet.	Inches.	Fathoms.	Feet.	Inches.
			Thill stone	1	5	9			
			Blue stone and hard girdles	0	3	5			
40	2	4	Coal	0	2	4	2	5	6
			Thill	0	0	7			
			Cashy parting	0	0	1			
			White post	2	4	7			
41	2	4	Coal	0	2	4	3	1	7
			Thill	0	4	5			
			Blue stone...	0	2	0			
			Whin	0	0	7			
			Grey post	0	0	8			
			Blue stone	0	1	10			
			Whin	0	0	4			
			Grey post	0	2	0			
			Blue stone	0	0	8			
42	0	4	Coal	0	0	4	2	0	10
			Thill	0	1	3			
			Blue stone and hard girdles	0	2	7			
			Thill	0	1	6			
			Blue stone	0	0	7			
			White post	0	0	6			
			Blue stone	0	0	4			
			Whin	0	0	5			
			Grey post	0	1	0			
			White post	0	1	9			
			Blue stone and hard girdles	0	2	0			
			Cashy parting	0	0	2			
			Whin	0	0	9			
			Blue stone	0	4	8			
43	2	8	Coal ... ... 2ft. 8in. } Stone Coal Seam.						
			Band ... ... 0 3 }						
44	0	5	Coal ... ... 0 5 }						
				0	3	4	3	2	10
			Thill	0	2	11			
			Blue stone	1	0	3			
			Whin	0	0	7			
			Blue stone and whin girdles	0	5	8			
			White post, with whin	0	1	8			
45	0	5	Blue stone	0	4	6			
			Coal ... ... 0ft. 5in. } Five-quarter Coal Seam.						
			Band ... ... 0 4 }						
46	2	10	Coal ... ... 2 10 }						
				0	3	7	4	1	2
			Thill	0	2	4			
			Blue stone and whin girdles	0	2	6			
47	0	10	Coal	0	0	10	0	5	8
			Thill	0	0	10			
	12	2	*Carried forward*	0	0	10	16	5	7

NO. OF SEAMS OF COAL.	THICKNESS OF SEAMS OF COAL. Ft.	In.	COAL MEASURES.	FATHOMS.	FEET.	INCHES.	FATHOMS.	FEET.	INCHES.
	12	2	*Brought forward*	0	0	10	16	5	7
			Blue metal stone	0	0	8			
			Black stone	0	2	10			
			Grey post	0	0	8			
			Blue stone and girdles	0	4	0			
48	2	6	Coal—Three-quarter seam	0	2	6			
							1	5	6
			Thill	0	1	1			
			Blue stone and post girdles	1	4	10			
			Grey post	0	1	1			
			Blue stone	0	1	1			
			Grey post	0	0	6			
			Blue stone	0	1	0			
			Whin	0	0	5			
			White post	0	2	1			
49	0	3	Coal	0	0	3			
							3	0	4
			Thill	0	0	3			
			Strong white post, with whin	6	1	9			
			Cashy parting	0	0	1			
			Strong white post, with whin	2	3	5			
50	3	3	Coal—Brockwell seam	0	3	3			
							9	2	9
	18	2					31	2	2

From the Beaumont Seam to the thill of the Brockwell Seam, is 31 fathoms 2 feet 2 inches, containing 18 feet 2 inches of coal, equal to 9·65 per cent.

The strata beneath the Brockwell Seam were explored by a borehole made at Chopwell Colliery (situated near Towneley), in the year 1795.

The following is the section :—

NO. OF SEAMS OF COAL.	THICKNESS OF SEAMS OF COAL. Ft.	In.	COAL MEASURES.	FATHOMS.	FEET.	INCHES.	FATHOMS.	FEET.	INCHES.
			Thill stone	3	1	3			
			Brown post	2	0	0			
			Black metal stone	0	2	0			
			Grey post	1	5	0			
			Black metal stone	0	0	5			
51	1	1	Coal	0	1	1			
							7	3	9
			Brown metal stone	0	1	0			
			Blue post	0	5	9			
			Dun whin	0	1	6			
			Cashy parting	0	0	1			
	1	1	*Carried forward*	1	2	4	7	3	9

No. of Seams of Coal.	Thickness of Seams of Coal. Ft.	In.	COAL MEASURES.	Fathoms.	Feet.	Inches.	Fathoms.	Feet.	Inches.
	1	1	*Brought forward*	1	2	4	7	3	[illegible]
			Strong white post	1	0	9			
			Blue metal stone	0	0	9			
			Strong post girdles	0	0	5			
			Black metal stone	1	1	7			
			Strong post girdles	0	0	5			
			Blue metal stone	1	4	4			
52	0	1	Coal	0	0	1	5	4	8
			Thill	0	0	10			
			Blue metal stone	0	2	10			
			Strong white post	0	2	6			
			Black metal stone	0	3	0			
			Strong white post	0	1	0			
			Black metal stone	0	1	8			
			Strong white post	0	1	0			
			Black metal stone	0	1	0			
53	0	1	Coal	0	0	1			
							2	1	11
			Black metal stone	0	1	4			
			Strong white post	1	3	4			
			Cashy parting	0	0	1			
			White post	0	1	11			
			Blue metal stone	0	0	7			
54	0	9	Coal	0	0	9			
							2	2	0
			Black metal stone, mixed with coal	0	0	6			
			Thill	0	0	9			
			Grey metal stone	0	2	2			
			White post	0	2	7			
			Cashy parting	0	0	1			
			White post girdle	0	0	8			
			Dun whin	0	2	0			
			Strong white post girdles	0	0	8			
			Black metal stone	0	1	9			
			Post girdle	0	0	5			
			Black metal stone	0	1	11			
			Post girdle	0	0	6			
			Blue metal stone	0	4	4			
			Strong white post	0	1	0			
			Grey metal stone	0	3	6			
			White post girdle	0	0	5			
			Grey metal stone	0	0	8			
			White post	0	2	7			
			Parting	0	0	1			
			Strong grey post	0	2	11			
			Parting	0	0	1			
			Strong white post	0	0	10			
			Grey post	0	2	4			
			Strong white post	1	0	6			
			Grey post	0	0	10			
55	0	2	Coal	0	0	2			
							[illegible]	4	3
	2	2	*Carried forward*	...	...	...	24	4	7

NO. OF SEAMS OF COAL.	[redacted] OF SEAMS OF COAL.		COAL MEASURES.	FATHOMS.	FEET.	INCHES.	FATHOMS.	FEET.	INCHES.
	Ft.	*In.*							
	2	2	*Brought forward*	...	...	...	24	4	7
			Dun post	0	5	0			
			Blue metal stone	0	0	8			
			Whin girdle	0	0	2			
			Grey post	0	1	2			
			Dun post	0	2	0			
			White post	0	2	2			
			Grey post	0	2	9			
			White post	0	2	2			
			Dun whin	0	2	4			
			Parting	0	0	2			
			White post	0	1	8			
			Blue metal stone	0	0	8			
			White post girdles	0	3	10			
			Blue metal stone	1	2	10			
			Grey post girdles	0	0	8			
			Blue metal stone	0	3	3			
			White post	0	2	11			
			Blue metal stone	0	3	0			
			Grey post	0	3	9			
56	0	9	Coal	0	0	9			
							7	5	11
			Grey post	0	1	9			
			White post	0	2	10			
			Brown post	0	0	11			
			Parting	0	0	2			
			Brown post	0	1	6			
			Parting	0	0	1			
			White post	0	3	1			
			Grey post	0	3	6			
			Blue metal stone	0	0	6			
			Grey post	0	1	8			
			Cashy parting	0	0	3			
			White post girdle...	0	0	4			
			Blue metal stone	0	3	6			
			Grey metal stone	0	1	9			
			Whin girdle	0	0	7			
			Blue metal stone	0	4	4			
57	0	3	Coal	0	0	3			
							4	3	0
			Thill	0	1	0			
			Brown post	0	0	11			
			Grey metal stone	0	0	11			
			Dun whin...	0	1	0			
			Parting	0	0	1			
			White post	0	4	2			
			Grey metal stone	0	1	4			
			White post	0	1	8			
			Grey metal stone	0	1	4			
			White post and grey metal	0	5	8			
			Black metal stone	0	2	10			
			Strong grey post	0	3	1			
	3	2	*Carried forward*	4	0	0	[illegible]7	1	6

No. of Seams of Coal.	Thickness of Seams of Coal. Ft.	In.	COAL MEASURES.	Fathoms.	Feet.	Inches.	Fathoms.	Feet.	Inches.
	3	2	*Brought forward*	4	0	0	37	1	6
			Post girdle	0	0	8			
			Strong grey post	0	1	8			
			Strong white post...	0	5	3			
			Black metal stone	0	3	2			
			Grey metal stone	0	2	3			
			Strong white post...	0	1	2			
			Strong brown post	0	3	1			
			Cashy parting	0	0	9			
			White post girdle...	0	0	7			
			Grey metal stone	0	2	7			
			White post	0	1	0			
			Blue metal stone	0	0	8			
58	0	5	Coal	0	0	5			
							7	5	3
			White post, with coal pipes	1	1	3			
			Blue metal stone	1	1	7			
			Dun whin...	0	1	6			
							2	4	4
	3	7					47	5	1

This borehole proves the coal measures to exist at least 47 fathoms 5 feet 1 inch further than recorded in the sections given above. This latter section contains 3 feet 7 inches of coal, equal to 1·24 per cent.

If the conclusion be correct, that the Brockwell Seam above named, and the Bitchburn Seam of the Auckland district are identical, we have a still greater depth of coal measures in the North of England, as proved by a boring made below the Bitchburn or Main Coal Seam at Witton Park, about $2\frac{1}{2}$ miles west of Bishop Auckland.

No. of Seams of Coal.	Thickness of Seams of Coal. Ft.	In.	COAL MEASURES.	Fathoms.	Feet.	Inches.	Fathoms.	Feet.	Inches.
50			Brockwell, Bitchburn, or main coal						
			Thill stone, with ironstone balls	1	1	9			
			Dark grey metal	0	2	0			
			White post, with partings	1	0	3			
			Brown and grey metal	2	3	6			
			Grey post, with partings	0	4	0			
			Grey metal, with girdles	1	3	0			
			Black metal	0	1	5			
51	0	4	Coal	0	0	4			
							7	4	3
			Light metal	0	5	2			
	0	4	*Carried forward*	0	5	2	7	4	3

No. of Seams of Coal.	Thickness of Seams of Coal. Ft.	In.	COAL MEASURES.	Fathoms.	Feet.	Inches.	Fathoms.	Feet.	Inches.
	0	4	*Brought forward*	0	5	2	7	4	3
			Dark metal, with ironstone bands and water	0	1	0			
			Grey metal, with girdles and water	0	5	8			
			Dark metal stone...	0	1	9			
			Coal, mixed with metal	0	0	6			
			Dark metal stone...	0	3	0			
52	1	0	Coal	0	1	0			
							3	0	1
			Grey post	0	4	11			
			White post, with grey metal partings	1	1	2			
			Blue metal	0	1	10			
			Scamy post and girdles	0	1	1			
			Blue metal	0	2	8			
			Dark metal and brown girdles	0	3	2			
			Grey metal stone	1	3	5			
			Black slate	0	0	4			
			Grey metal and girdles	0	3	3			
			White post, with partings	1	5	6			
			Dark metal	0	1	0			
			Slate and coal	0	0	4			
			Dark metal	0	1	3			
53	1	8	Coal	0	1	8			
							8	1	7
			Thill stone	0	0	10			
			Blue metal and girdles	0	4	11			
			White post and whin girdles	3	3	0			
			Blue metal and girdles	2	2	9			
			Grey post and metal partings	0	3	7			
			Black metal	0	2	3			
			Blue metal	0	0	3			
54	1	8	Coal, with 3 inches of splint in middle	0	1	8			
							8	1	3
			Grey metal stone	0	2	7			
			Blue metal and ironstone balls	0	3	5			
			Blue metal and post girdles	3	1	6			
			White post	0	3	3			
			Mild white post	0	3	11			
			Blue metal, grey girdles, and water	2	1	8			
			Dark metal	0	1	6			
55	0	7	Coal, with water	0	0	7			
							8	0	5
			Grey metal, with girdles	0	5	7			
			Bastard whin	0	1	1			
			Blue metal	1	0	9			
			Dark metal	0	0	7			
			Whin	0	1	2			
			White post	0	1	6			
			Grey post	1	0	1			
			Blue metal	2	0	3			
			Grey post	2	0	7			
			White post and water	10	1	3			
			Blue metal and whin girdles	2	1	11			
	5	3	*Carried forward*	20	2	9	35	1	7

NO. OF SEAMS OF COAL.	THICKNESS OF SEAMS OF COAL. Ft.	In.	COAL MEASURES.	FATHOMS.	FEET.	INCHES.	FATHOMS.	FEET.	INCHES.
	5	3	*Brought forward*	20	2	9	35	1	7
			Grey bastard whin	4	2	0			
			Blue metal	0	1	6			
			Black and grey metal	1	0	5			
			Grey whin girdle	0	0	3			
			Blue metal	0	1	5			
			Grey whin girdle	0	0	9			
			Mild white post	11	4	9			
			Hard white post and metal partings	1	0	0			
			Blue and grey metal, with girdles	0	5	11			
			Blue metal, with thin bands of ironstone	1	3	2			
			Whin and grey metal stone, with blue metal partings and water	3	2	0	45	0	11
	5	3					80	2	6

This borehole proves the coal measures 32 fathoms 3 feet 5 inches deeper than the Chopwell borehole. The section of 80 fathoms 2 feet 6 inches contains 5 feet 3 inches of coal, equal to 1·09 per cent. At Backworth Colliery, about 4 miles north of Wallsend, a boring was made below the Low Main, to the depth of 100 fathoms: in this section were 15 seams of coal, of the united thickness of 16 feet 7 inches, a seam of 1 foot 3 inches being cut at the bottom of the borehole.

The following is a summary of the above :—

	FATHS.	FT.	IN.
1. Coal strata above the thill of the Bensham seam, as proved by sinking at Monkwearmouth Colliery	210	3	$6\frac{1}{4}$
2. Ditto between Bensham and Low Main thill, as proved by boring at Hebburn	22	1	0
3. Ditto between Low Main and Beaumont Seam thill, as proved by boring at Wallsend Colliery	23	2	10
4. Ditto between Beaumont and Brockwell Seam thill, as proved by sinking at Towneley Colliery	31	2	2
5. Ditto so far as at present explored, being proved by boring below the Bitchburn, (Brockwell) Seam, at Witton Park Colliery	80	2	6
	368	0	$0\frac{1}{4}$

This is equal to 2,208 feet, and in this depth, (taking the Witton Park Section of the lower measures) there are 55 seams of coal, varying in thickness from 1 inch to 5 feet 5 inches, their aggregate being 77 feet $5\frac{1}{4}$ inches, equal to 3·81 per cent. of the whole thickness of coal measures explored.

The preceding section may be divided as follows :—

	FT.
Upper Coal Shales, &c., containing 10 seams of coal, from 1 to 14 inches thick, to roof of coal No. 11...	360
Coal series, containing 40 seams of coal, from 2 inches to 5 feet 5 inches thick, to thill of Brockwell seam	1365½
Lower Coal Shales, &c., containing 5 seams of coal, from 4 to 20 inches thick	482½
	2208

It will be observed, on examination of the sections of the lower shales, &c., that there is nothing to warrant the conclusion that the bottom of the coal measures is approached. We have already seen, by examples given, that in the coal measures of the Carboniferous system, there are usually marked subdivisions into series productive of coal, separated by others barren of coal, or nearly so. Whether or not the productive series now being worked in Northumberland and Durham is the lowest of that description in the coal measures, is, as yet, unproved.

The strata associated with coal, are either siliceous, argillaceous, or carbonaceous, or intermediate between these.

Siliceous strata include all those locally known as sandstone, post (rock or greys), and whin, according to their different degrees of hardness. The strata designated in the above sections by the latter term, do not, as is sometimes erroneously stated, consist of basalt, but are merely a very hard compact siliceous stone, sometimes resembling coarse flint or chert.

Argillaceous strata comprise all those designated as metal (shale), and vary also in hardness and colour. Some of these strata, more particularly those which form the seat or thill of coal seams, when ground and mixed with water, form a clay which is moulded and burnt into bricks of a very refractory nature, and well adapted for the lining of blast and other furnaces exposed to intense heat. Beds of this shale, or, as it is termed, sagre clay, or fireclay, are frequently interstratified as "bands" with seams of coal, in some instances making them workable to profit, when otherwise they would be valueless.

Bands and nodules of argillaceous ironstone are also frequent in the shales of the coal measures; they seldom attain any considerable thickness, bands of from one to three or four inches being most frequently found, and becoming workable in proportion to their proximity to each other, or to seams of coal, in conjunction with which they may be worked.

The following is the average analysis of the argillaceous ores worked by the Dowlais' Iron Company, at Merthyr Tydfil (Truran) :—

Carbonate of iron	67·14
Silica	23·96
Alumina	4·99
Carbonaceous matter	2·10
Carried forward	98·19

Brought forward ...	98·19
Lime ...	0·19
Manganese ...	0·60
Phosphoric acid ...	trace
Moisture and loss ...	1·02
	100·00
Metallic iron ...	31·87

Average analysis of Scotch argillaceous ores, from the neighbourhood of Crossbasket, by Dr. Colquhoun :—

Protoxide of iron ...	43·91
Peroxide of iron ...	0·36
Carbonic acid ...	31·87
Protoxide of Manganese ...	0·08
Lime ...	3·08
Magnesia ...	3·83
Silica ...	9·34
Alumina ...	4·37
Carbonaceous matter ...	2·05
Sulphur ...	0·06
	98·95
Metallic iron ...	33·93

Black stone, and black metal stone, are sometimes so highly carbonaceous as to burn with flame; they lose little in bulk, and leave behind a mixture of silica and alumina; in fact, this latter substance is occasionally in sufficiently large quantity to render the substance which contains it available for the manufacture of alum, the process being similar to that formerly described. These inflammable shales afford, on distillation, a crude petroleum, varying in quantity according to their richness; some of them yield as much as 20 gallons to the ton. The Torbane Hill mineral (pronounced by some authorities to be coal, and by others shale) yields, when distilled at a low red heat, from 50 to 70 gallons of paraffin oil to the ton. The celebrated Blackband ironstone of the neighbourhood of Glasgow, is a ferruginous black metal; its great value as an ore being enhanced by the facility which its bituminous nature affords to its calcination.

The appearance of this ironstone resembles that of a heavy parrot, or cannel coal. It comes away in two beds, the upper about four inches thick, the lower and more solid and dense part ten inches. It lifts in lengthened oblong squares, stretching out like a pavement, and sometimes in triangular masses. Its fracture is grey black, striped with whitish-coloured laminæ. The ironstone rests upon a bed of parrot coal, one inch thick, and parting in strips of about two inches in breadth. Below this is

found a soft fine clay, which serves for good holing. The incumbent strata are a coaly shale immediately over the ironstone; and above this, a fine parrot or cannel coal, capable of receiving a good polish. (Mushet's Papers on Iron and Steel, 1840.)

Analysis of Mushet's Blackband, from the neighbourhood of Airdrie, by Dr. Colquhoun :—

Protoxide of iron ...	53·03
Carbonic acid ...	35·17
Lime ...	3·33
Magnesia ...	1·77
Silica ...	1·40
Alumina ...	0·63
Peroxide of iron ...	0·23
Calcareous, or bituminous matter ...	3·03
Moisture and loss ...	1·41
	100·00
Metallic iron ...	41·00

Analysis of Cairn Hill Blackband, by Dr. Colquhoun :—

Protoxide of iron ...	40·77
Carbonic acid ...	26·41
Lime ...	0·90
Magnesia ...	0·72
Clay ...	10·10
Coaly matter ...	17·38
Iron Pyrites ...	2·72
Water ...	1·00
	100·00
Metallic iron ...	33·00

The whole of the strata of the coal measures contain organic remains in greater or less abundance—the argillaceous the most abundantly. They are found in especial profusion in the shales overlying some of the seams of coal.

Plate 13, fig. 1 (Gyracanthus spine), and fig. 2 (Stigmaria), were found at the distance of about 200 yards from each other, in the roof of the Five-quarter Seam at Black Boy Colliery, near Bishop Auckland.

Plate 13, figs. 3 and 4, are teeth of Ctenodus, from the roof of the Low Main Coal Seam at Newsham Colliery, Northumberland; and fig. 5, Lepidostrobus, found in the same locality, is given in order to show the relation between the fauna and flora of the period. For these I am indebted to the kindness of Mr. T. P. Barkas, of Newcastle-upon-Tyne.

The fruit (Trigonocarpum Nöggerathi), Plate 14, fig. 2, was obtained from the sandstone, or post, overlying the High Main Coal Seam at Holywell Colliery, about six miles north-east of Newcastle-upon-Tyne.

Plate 14, figs. 3, 4, and 5, are drawings of shells and plants, from the strata sunk through at Shotton Colliery.

Plate 14, is an Anthracosia, from the roof of the Bitchburn Seam at West Auckland Colliery. A similar bed of shells, forming the roof of the Brockwell or Horsley Wood Seam, at Wylam, points to an identification of these two seams with each other.

Plate 15 represents specimens of Pecopteris, found in the strata above the Five-quarter Seam in sinking Shotton Pits.

Plate 16 is a drawing of a Pecopteris, from the South Staffordshire coal field, for which I am indebted to Mr. Henry Johnson, of Dudley.

Plate 17, fig. 1, is a drawing of Prestwichia Rotundata, associated with Neuropteris Elegans, found at Camerton Colliery, in the shale overlying the Great Vein, or uppermost workable seam of the Radstock series of the Bristol coal field. Figs. 2, 3, 4, 5, and 6, represent plants from the neighbourhood of Radstock.

The subject of organic remains, particularly as regards the flora of the coal measures, is most voluminous, and one upon which much has been ably written, and, of course, impossible to enter into at length within the bounds at present prescribed to us. The reader is referred to the elaborate work of Messrs. Lindley and Hutton, as an excellent aid in the prosecution of his studies in this most interesting branch of Natural History.

The whole of the seams of coal worked in the Newcastle coal field are not found in a workable state in the section above given. It may, in fact, be remarked, that in no locality are the whole of the generally workable seams found in perfection. The seams not only vary in thickness, but also in every respect, in sections taken at comparatively short distances from each other. In some situations they are richly bituminous and caking, in others carbonaceous and free burning; in some they are soft and brittle, and in others hard and compact.

The same seams of coal also exist in different localities, under different names; their identity will be discovered on reference to plate 18, which is collated with the synopsis published by Mr. Buddle, in the "Transactions of the Natural History Society of Newcastle-upon-Tyne," 1831.

The seams worked, in the order of their stratification, are as follows:—

1.	The *High Main Seam*	No. in section.
2.	The *Five-quarter Seam*...	No. 26 & 27
3.	The *Main Coal Seam*	No. 28
4.	The *Bensham Seam*	No. 29, 30, & 31
5.	The *Hutton Seam*	No. 34
6.	The *Plessey Seam*	No.
7.	The *Beaumont Seam*	No. 37, 38, & 39
8.	The *Stone Coal Seam*	No. 43 & 44
9.	The *Lower Five-quarter Seam*...	No. 45 & 46
10.	The *Three-quarter Seam*	No. 48
11.	The *Brockwell Seam*	No. 50

1.—The HIGH MAIN SEAM of the Tyne Collieries is found at the following depths from the surface :—

COLLIERY.	FATHS.
Percy Main	133½
Hebburn	131
Killingworth	115
Wallsend	111
Burradon	80
Tyne Main	53
Backworth North Pit	52½
Seaton Delaval	32
St. Lawrence	34½
Hartley	24
Earsdon	12

At these Collieries, with the exception of Seaton Delaval and Hartley, the High Main Seam is of a rich and caking quality: it burns rather quickly, makes a hot fire, and leaves but little ash, of a darkish colour. At Seaton Delaval and Hartley it loses richness, burns openly, leaving a white ash, and is a pretty good steam coal. The prime districts of the High Main are now much exhausted, but still afford the best coals shipped from the Tyne Collieries, for household use. The whole of the workings in the High Main Seam south of the Ninety Fathoms Slip, where under the level of the Tyne, were, until lately, inundated. Operations, however, have been, and are, in progress at Wallsend, by which their entire drainage is expected to be effected at no distant period.

Mr. Buddle (Parliamentary Evidence, 1835,) gave the following as being the section of the High Main Seam at Wallsend Colliery :—

ROOF, BLUE METAL.	FT.	IN.
Good coal...	6	7½
Ground coal, not good	2	2
	8	9½

The upper part only was worked, and, excepting what was left in barriers, the coal has been exhausted.

The High Main Seam at Backworth Colliery presents the following section :—

	FT.	IN.
Coal, strong	5	11
Soft band	0	1
Coal, very coarse...	1	6
Stone band	0	8
Coal, coarse and mixed with pyrites	2	6
	10	8

But here, as at Wallsend, a great portion is left in the mine; the upper 5 feet 11 inches only is worked, the rest being unsaleable. At Seaton Delaval Colliery, the following is the section:—

	FT.	IN.
Coal	0	6
Coarse coal	0	8
Coal	4	8
Coarse coal	0	10
	6	8

The general thickness of the High Main Seam is from 5 to 6 feet of good coal. A little to the south of the Tyne, it is interstratified with a bed of stone called the Heworth Band, which, in Tyne Main Colliery, is in some places scarcely discernible, but which thickens towards the south, and has hitherto rendered the seam unworkable a short distance from the River.

The average specific gravity of the High Main Coal may be deduced from the following statement, contained in the appendix to the report of the select committee of the House of Commons on the state of the coal trade in 1830.

The specific gravity of the different specimens was ascertained by a hydrostatic balance, which weighed to the 1,000th part of a grain.

Distilled water was used, and the air of the room was at a mean temperature of 61° Fahrenheit.

Russell's Wallsend, (Wallsend Colliery)	1·26660
Riddell's do., (Coxlodge do.)	1·25000
Northumberland do. (Backworth do.)	1·26365
Newmarch's do., (Fawdon do.)	1·26469
Heaton do., (Heaton do.)	1·26310
Hotspur do., (Earsdon do.)	1·26621
Bewicke's do., (Percy Main do.)	1·25802
Killingworth do., (Killingworth do.)	1·26262
Mean	1·26184

A cubic foot of coal from the High Main Seam weighs, therefore, 78·64lbs. avoirdupois.

I have been favoured with the results of several experiments which have been made, in order to ascertain the time of burning portions of coal from different seams in an open fire, and also the quantity of residuum left in each case. The quantity of

coal used was, in each experiment, 48lbs.; with the High Main Coal, the results were as follows:—

SPECIMENS.	TIME OF BURNING.		RESIDUE.		PROPORTION OF RESIDUE PER CENT.
	H.	M.	LB.	OZ.	
No. 1.	8	42	1	1	2·140
No. 2.	7	45	0	10	1·302
No. 3.	8	5	0	6	·781
do.	7	30	1	0	2·983
Average	8	0	0	12¼	1·576

These results were intended to be approximations to the truth, sufficiently near to give a good idea of the comparative durability and cleanness of coal from different localities.

The High Main Seam corresponds to the Three-quarter Seam of the southern and eastern part of the coal field, and to the Shield Row Seam of the western division. It is not at present of much value, however, where it is known under any other denomination than that of the High Main. It is found of good household quality between the line of the Briardean Burn and Heworth Slip dikes; but exists in its most perfect state between a line a little north of the Ninety Fathom Slip dike and the River Tyne. Its western outcrop is on the declivity of a hill near Benwell. In the Benwell and Fenham estates a large tract of the High Main Seam was destroyed by a conflagration in the middle of the sixteenth century.

2.—The Five-Quarter Seam of the Wear and Tees collieries, corresponding with the Grey Seam of the Cramlington district, is the next in order.

In the neighbourhood of Newcastle it consists of two seams, namely, the *Metal Coal* and the *Stone Coal* seams, which lie seven and fourteen fathoms respectively below the High Main Seam, neither of which have as yet been worked. Where united, and forming the Grey Seam, they have been partially worked near Blyth as a steam coal.

The depth from the surface to the Five-Quarter Seam, where it exists in a workable state, is as follows:—

COLLIERY.	FATHOMS.	
Haswell	90	These pits pass through the Permian formation before entering the coal measures.
Shotton	125	
Thornley	84½	
Wingate Grange	74	
Castle Eden	119	
Coxhoe	34	
Little Chilton	37	
Newbottle	84	
Pittington	40	

COLLIERY.	FATHOMS.
Sherburn Hill	38
Pontop	31
Blackboy	25
Adelaide's	37½

The coal from this seam is generally of a rich caking quality, and is more durable than that from the High Main Seam. It makes a very hot fire, leaving ash of a dark colour, frequently red, but in greater quantity than is left by the High Main coal. It is also harder, and works larger, and bears carriage better in consequence. In some places, as at Newbottle and towards the banks of the Wear, east of Durham, it is less bituminous, burns to white ashes, and is a good steam coal.

The following is a section of the Five-Quarter Seam at Shotton Colliery :—

ROOF BLUE METAL.	FT.	IN.
Splint Coal	0	2
Coal	3	8½
Splint	0	1
	3	11½

SECTION AT NEWBOTTLE COLLIERY.	FT.	IN.
Coal	1	0
Coarse Coal	2	5
It is here a very hard coal.	3	5

SECTION AT BLACKBOY COLLIERY.	FT.	IN.
Coal	3	8
Splint	1	10
	5	6

SECTION AT PONTOP COLLIERY.	FT.	IN.
Coal	0	7
Jet	0	3
Coal	3	2
Splint	0	8
Coal	1	6
	6	2

In the Pontop district, this seam yields good second-rate coals, and has been extensively worked.

A great proportion of the first-class coals from the Wear and Tees Collieries is worked out of the prime districts of the Five-Quarter Seam. It lies in the greatest perfection beneath the magnesian limestone, and in its immediate neighbourhood.

Its usual thickness is from 3 feet 4 inches to 3 feet 10 inches of good coal, workable for household use. It is often associated with a seam of splint, lying beneath and

contiguous to it, which, when thick enough to afford large coals, is frequently worked along with the best part of the seam, and sold as a steam coal, for which purpose it is very well adapted.

Mr. Buddle, in his synopsis of the Newcastle coal field (Transactions of Natural History Society, Newcastle-upon-Tyne, vol. 1), said of the Five-Quarter Seam :—"This seam yields coals of inferior quality : has been extensively worked in some parts of the district, but is not workable to profit in other parts." Not more than three or four years after this, the working of the Five-Quarter Seam was commenced at Thornley Colliery, sunk with the intention of working the Hutton Seam, beneath, but which was found to exist in (at that time) an unfavourable condition for working. The hardness and excellent quality of the Five-Quarter coals, however, soon stamped them as being of first-rate character, and they have been and yet are considered as being inferior to none.

The Hartlepool, Tees, Caradoc, Kelloe, &c., Wallsend, are principally worked from this seam.

The following are the results of burning the Five-Quarter Coal :—

SPECIMENS.	TIME OF BURNING.		RESIDUE.		PROPORTION OF RESIDUE PER CENT.
	H.	M.	LB.	OZ.	
No. 1.	9	23	1	8	3·125
No. 2.	10	33	0	12	1·562
No. 3.	9	10	1	0	2·083
Average	9	42	1	1	2·256

3.—The next seam is the YARD COAL of the Tyne, the Brass Thill of the Beamish and Pontop districts, and the Main Coal of the Wear and Tees Collieries. Its position is from 15 fathoms to immediately beneath the Five-Quarter Seam : in the Pontop district, the two seams are only separated by a band of 18 inches. On the Tyne, the Yard Coal has not hitherto been much worked, but as found in the Hartley district, it is 3 feet thick, and is an excellent steam coal.

Its depth from the surface is as follows :—

COLLIERY.	FATHOMS.
Hetton	108½
Castle Eden	126
Shotton	142
Pittington	47½
Coxhoe	43½
Blackboy	40
Pensher	88½
Oxclose	43½
Pontop	40

COLLIERY.	FATHOMS.
Earsdon	$40\frac{1}{2}$
Backworth	80
Seaton Delaval	$62\frac{1}{2}$

This seam, where worked south of the Tyne, produces coals varying from first to second household quality: it is harder than the High Main Seam of the Tyne, when the latter is in its household condition, but resembles it in many respects.

It makes a very hot, cheerful, rather open burning fire, leaves little dark ash, and burns rather quickly away.

It exists in perfection in the Auckland district, supplying the Tees and Adelaide's Wallsend Coals.

Under the name of the Brass Thill Seam, it is not nearly so hard, but of good quality, and in the eastern parts of Durham, the Wear Main Coal is a strong coal, working large, but its quality is rather inferior.

SECTION AT HETTON COLLIERY.

	FT.	IN.
Coal	1	8
Band	0	1
Coal	4	9
	6	6

SECTION AT CASTLE EDEN COLLIERY.

	FT.	IN.
Coal	1	4
Band, fireclay	0	$7\frac{1}{2}$
Coal	3	0
Parting		"
Coarse Coal	0	7
	5	$6\frac{1}{2}$

The lower 7 inches is not used for household coal.

SECTION AT COXHOE COLLIERY.

	FT.	IN.
Coal	1	4
Band	0	5
Coal	2	7
	4	4

SECTION AT BLACKBOY COLLIERY.

	FT.	IN.
Coal	1	4
Parting	0	$0\frac{1}{2}$
Coal	3	$11\frac{1}{2}$
Splint Coal	1	10
	7	2

The splint is much used for lime-burning, for which purpose it is worked, when required.

SECTION OF THE BRASS THILL SEAM AT BEAMISH COLLIERY.

	FT.	IN.
Coal	4	8

SECTION OF THE YARD COAL AT SEATON DELAVAL COLLIERY.

	FT.	IN.
Coal	3	1

The following were the results obtained by burning coals from this seam :—

SPECIMENS.	TIME OF BURNING.		RESIDUE.		PROPORTION OF RESIDUE PER CENT.
	H.	M.	LB.	OZ.	
No. 1. Yard Coal	6	10	1	0	2·083
No. 2. do.	9	35	2	0	4·166
Average	7	52	1	8	3·124
No. 1. Auckland Main Coal ...	8	11	1	0	2·083
No. 2. do. ...	9	30	1	0	2·083
Average	8	50	1	0	2·083

4.—The BENSHAM SEAM of the Tyne, called the Maudlin Seam at the collieries on the banks of the Wear, is the next in succession. It is from 10 to 14 fathoms below the Wear Main Coal or Tyne Yard Seam.

Its depth from the surface is as follows :—

COLLIERY.	FATHS.
Monkwearmouth	264
Ryhope	253½
Jarrow	175
Hebburn	167
Wallsend	145
Earsdon	54
Backworth	93
Oxclose	80
Pensher	99

This seam produces coals from the best second-class to very inferior quality : it is, in general, rather tender, and much interstratified in places with bands of splint coal and slate. It is much used for the manufacture of gas.

The following is a section at Monkwearmouth Colliery :—

	FT.	IN.
Coal	3	6
Splint Coal	0	2
Coal	1	7¼
Band	0	1
Coarse Coal	0	7
Coal and Stone	3	6
	9	5¼

The lower part of the seam, consisting of 4 feet 2 inches, is of no value, being very inferior.

SECTION AT RYHOPE COLLIERY.

	FT.	IN.
Coal	4	0
Splint Coal	0	2
Coal	3	0
Stone	0	2
Coarse Coal	4	10
	12	2

The lower 5 feet is not worked.

SECTION AT JARROW COLLIERY.

	FT.	IN.
Coal	3	0¼
Coarse Coal	0	6
Coal	3	0
	6	6¼

SECTION AT BACKWORTH COLLIERY.

	FT.	IN.
Coal	2	5
Black Stone	0	6
Coal	1	3
	4	2

The Bensham Seam has not yet been worked in this district.

SECTION OF THE MAUDLIN SEAM AT OXCLOSE COLLIERY.

	FT.	IN.
Coal	2	8
Splint Coal	0	1½
Coal	1	4½
Parting	0	0½
Coal	0	7½
	4	10

The Bensham Seam does not extend over a very large portion of the coal field in its best state : its quality improves towards the east, and under the sea will probably be a most valuable seam of coal.

The mean specific gravity of the Hilda Wallsend Coals wrought from the Bensham Seam is 1·26087, a cubic foot weighing 78·578 lbs.

The following results were obtained by burning coals from this seam :—

SPECIMENS.	TIME OF BURNING. H.	TIME OF BURNING. M.	RESIDUE. LB.	RESIDUE. OZ.	PROPORTION OF RESIDUE PER CENT.
No. 1.	9	35	2	8	3·645
do.	10	0	1	0	
No. 2.	9	0	2	0	3·645
do.	10	15	1	8	
No. 3.	10	0	2	1	4·296
No. 4.	10	52	3	4	5·468
do.	10	45	2	0	
Average	10	3	2	0$\frac{5}{7}$	4·263

The Bensham or Maudlin Seam, in conjunction with the Five-Quarter Seam of the Tyne Collieries (a hitherto unworked seam), which corresponds to the Low Main Seam of the collieries on the banks of the Wear, forms the Low Main of the collieries south of that river, and the Hutton Seam of the Pontop and Beamish district.

Under this form its depth from the surface is as follows :—

COLLIERY.	FATHOMS.
Hetton ...	130
Castle Eden ...	148
Pittington ...	74
Pontop ...	70

Its quality is variable : at Hetton and the surrounding district it is a strong coarse coal, suitable for steam purposes ; nearer Durham, as at Pittington, &c., it is of much finer quality, being almost as good as the Hutton Seam ; and at Pontop and Tanfield Collieries, though rather tender, it yields coals of the finest quality, and, being free from any admixture of pyrites or other impurity, it is preferred in metallic manufactures. This coal has supplied the celebrated Pitt's Tanfield Moor Coals for upwards of a century, and is now greatly exhausted.

SECTION OF THE LOW MAIN SEAM AT CASTLE EDEN COLLIERY.

	FT.	IN.
Coal and Splint ...	0	7
Parting ...	...	
Coal ...	1	5
Coarse Coal and Splint ...	0	4½
Coal ...	1	11
Slaty band ...	0	2
Coal ...	0	3
	4	8½

There is a very great resemblance between this seam and the Bensham Seam of the Tyne, and considerable doubts may be reasonably entertained as to whether it ought not to be referred entirely to that seam.

SECTION AT PITTINGTON COLLIERY.

	FT.	IN.
Coal ...	3	6½
Black Stone ...	0	2½
Splint Coal ...	0	3½
	4	0½

SECTION AT TANFIELD MOOR COLLIERY.

	FT.	IN.
Coal ...	6	3
Black Stone ...	0	5
Coal bad and scary ...	1	0
	7	8

SECTION AT PONTOP COLLIERY.

	FT.	IN.
Coal	2	6
Band	0	3
Coal	3	0
	5	9

5.—The Low Main Seam of the Tyne, the Hutton Seam of the Wear, and the Low Main or Main Coal of the Beamish and Pontop district, lies from 8 to 25 fathoms below the seam last described.

Its depth is as follows :—

COLLIERY.	FATHOMS.
Bedlington	100
Seghill	75
Cowpen	92
Bebside	94
Hartley	53
Earsdon	68½
Felling	100
Pensher	121
Haswell	155
Castle Eden	173
Pittington	89½
Shincliffe	72
Pontop	78
Towneley	8

The following is a section at Bedlington Colliery :—

	FT.	IN.
Black Stone	0	1
Cannel Coal	0	1
Coarse Coal ("Grey" Coal)	0	5
Parting		"
Coal	5	1
Band	0	3
Coarse Coal	0	6
	6	5

In this district, fine specimens of fish remains have been obtained from the roof of the Low Main Seam.

SECTION AT HARTLEY COLLIERY.

	FT.	IN.
Coarse Coal	0	1½
Coal	3	10½
	4	0

SECTION AT WEST CRAMLINGTON COLLIERY.

	FT.	IN.
Jet ("Grey" Coal)	0	3
Coal	5	1
Slaty Coal	0	7
Grey Metal Band	0	2
Coal	0	2
	6	3

In the district from which the above sections are taken, the Low Main Seam yields coals of first-class steam quality. They work large, burn quickly, and leave a white ash, and do not produce any clinker.(1)

SECTION AT FELLING COLLIERY.

	FT.	IN.
Coal	2	2
Parting	0	0¼
Coal	3	2
Parting	"	
Coarse Coal	0	6
	5	10¼

The coarse coal at the bottom is left: the seam here is tender and burns to white ashes, but as a gas coal is in great request. The small coal is also much used by blacksmiths, on account of its freedom from pyrites.

SECTION AT HASWELL COLLIERY.

	FT.	IN.
Coal	4	7
Parting	0	1½
Coarse Coal	1	3
	5	11½

The bottom coal is worked as a steam coal. The upper part of the seam, 4 feet

(1) The West Cramlington, Seghill, and Cramlington Seam, is divided by a band near the boundary between Cramlington and Seaton Delaval Collieries. This band thickens towards the east, and at Hartley Colliery is 8 or 9 fathoms thick. It is probable that the same band encircles the Cramlington district on the south and west also; in fact, that a seam of coal beneath the Low Main Seam of the Tyne (perhaps No. 31 in the General Section) rises up to the north, and forms with it the Low Main Seam of Seghill, Cramlington, the northern division of Seaton Delaval, and of the districts northward of these. The following is a section of the Low Main Seam at Seaton Delaval Colliery, near to the Cramlington boundary :—

	FT.	IN.
Coal	3	0
Band	0	4
Coal	2	0
	5	4

The upper part of this seam thickens also to the east and forms the Hartley Seam, of which a section has been given above. The Hutton Seam is divided by a band in Croxdale Colliery, in the south part of Shincliffe, Whitwell, Haswell, and Shotton Collieries, which thickens to the south and divides it into two distinct seams, which at Coxhoe are 4 fathoms apart, the upper seam being 2 feet 2 inches thick, and the lower seam 2 feet 11 inches, of which the bottom 4½ inches are coarse coal. With some exceptions, it may be stated that the south boundary of the Hutton Seam in a good state is somewhere about the Tudhoe or Hett Whinstone Dike; at least, wherever the Hutton Seam has been proved to the south of this dike, it has been found either to be inferior in strength or in thickness, or else divided by a band which soon renders the seam unworkable by one process.

7 inches thick, is in this district of the first household quality, and works large. The Hutton Seam of this neighbourhood is the most valuable seam producing household coal of the coal field, all the attendant circumstances of thickness, facility of being worked, and distance from the port of shipment, together with its fine quality, being taken into consideration. The High Main Seam of the Tyne, in its prime districts, could perhaps have competed successfully with the Wear Hutton Seam, but, as before stated, these are greatly exhausted.

SECTION AT SHINCLIFFE COLLIERY, NEAR DURHAM.

	FT.	IN.
Coal	4	1
Band	0	2½
Coarse Coal	1	1½
	5	5

The bottom coal is not worked: the upper part is a good household coal.

SECTION AT PONTOP COLLIERY.

	FT.	IN.
Coal	2	10
Parting		"
Coal	1	0
	3	10

The Low Main of the Tyne or Hutton Seam of the Wear is undoubtedly (so far as yet known) the most valuable seam in the coal field. It has been found in a workable state over a much larger extent of country than any other seam. Varying in its character in different districts, it affords best coals of every description, whether adapted for steam purposes, for the manufacture of gas, or for household use. It yields the Cramlington and Hartley steam coals from the district north of the Briardean Burn Slip Dike, burning very openly and quickly away, leaving a white ash, and no slag on the fire bars; the Felling, Peareth and Pelton gas coals, from the south bank of the Tyne to the neighbourhood of the Wear and to Chester-le-Street, where it is tender and very bituminous; and the Lambton's, Stewart's, Hetton, and Haswell, &c., Wallsend coals from beneath the magnesian limestone and the districts bordering thereupon, which as a household coal, holds the highest position, and is remarkable for its richness, cleanliness, and durability. It is not so hard, and in consequence does not bear carriage quite so well as the coal from the Five-Quarter Seam, but in quality it is decidedly superior.

In fact, with the exception of the district south of the Hett Whinstone Dike, the Low Main or Hutton Seam is found generally in a workable state over nearly the whole of the great northern coal field of Northumberland and Durham.

The specific gravity of the Cramlington coal is 1·27011, and the weight per cubic foot 79·148 lbs. avoirdupois.

Of the household coals, the specific gravities are as follows :—

Russell's Hetton	1·26312
Lambton's Wallsend	1·26660
Stewart's do.	1·25885
Hetton do.	1·26031
Average	1·26222

And the weight of a cubic foot is 78·633 lbs.

The trials by burning coals from this seam gave the following results :—

DESCRIPTION.	SPECIMENS.	TIME OF BURNING. H.	M.	RESIDUE. LB.	OZ.	RESIDUE PER CENT.
Steam Coal ... (white ash) ...	No. 1.	8	55	1	0	2·083
	No. 2.	8	45	1	3	2·474
	Average ...	8	50	1	1½	2·278
Household Coal... (dark ash) ...	No. 1.	12	30	0	14	1·823
	No. 2	10	5	0	10	1·301
	No. 3.	12	15	1	8	3·125
	Average ...	11	36	1	0	2·083
Coking & Gas Coal (white ash) ...	No. 1.	11	20	1	8	3·124
	No. 2.	11	0	1	4	2·604
	No. 3.	13	26	2	6	4·948
	Average ...	11	55	1	11	3·559

6.—The Plessey Seam.

In the district contiguous to the River Blyth, in Northumberland, an excellent seam of steam coal is found at the following depth :—

COLLIERY.	FATHOMS.
Cowpen	102
Bebside	107½

SECTION AT COWPEN COLLIERY (BORING).

	FT.	IN.
Coal	2	9
Band	0	1
Coal	0	11
	3	9

SECTION AT BEBSIDE COLLIERY.

	FT.	IN.
Coal	4	3

7.—The next seam is the Beaumont Seam of the Tyne, called also the Harvey's Low Main, the Towneley, Engine and Barlowfield Seam, and in the Auckland and

Etherley district, the Yard Coal Seam. It lies from 20 to 35 fathoms below the Hutton Seam, and at the following depths below the surface:—

COLLIERY.	FATHOMS.
Elswick	100
Sheriff Hill	134
Haswell	176
Thornley	166
Wylam	7
Towneley	51
Blackboy	108
St. Helens Auckland	35

SECTION AT ELSWICK COLLIERY.

	FT.	IN.
Coal	2	4
Band	1	11
Coal	0	8
	4	11

SECTION AT TOWNELEY COLLIERY.

	FT.	IN.
Cannel or Splint	0	7
Coarse Coal	0	2½
Coal	2	11
	3	8½

It is here a good gas coal, the cannel adding materially to its value for gas making.

SECTION AT THORNLEY COLLIERY.

	FT.	IN.
Coal	3	8

SECTION AT ST. HELENS AUCKLAND.

	FT.	IN.
Coal	0	11
Splint Coal	0	0½
Coal	1	10½
Band	0	1½
Coal	0	8
	3	7½

The Beaumont Seam has been bored to at some of the Tyne collieries, but it still remains unopened below Newcastle Bridge. This seam produces coal of good quality, and, with few exceptions, uniform throughout the coal field: it yields second-class coals for household use, and the small screened out is well adapted for the manufacture of coke: it is also a good gas coal.

In the Towneley district, many very fine specimens of fish remains, similar to those found above the Low Main at Cowpen, have been found above the Towneley Seam. The fact seems to be almost invariable that fish remains are found in black metal overlying seams of coal; and the great frequency of the seams above which

they are found being cannel or splint in their upper part may probably throw some light upon the circumstances which occasioned the difference between cannel or splint and ordinary coal. Where fish remains abound, those of plants are rare, and *vice versâ.*

The seams below the Beaumont Seam are at present only known westward of the meridian of Newcastle. They are of pretty good quality, but tender: they produce second or third-rate household coals, but make excellent coke.

8.—The Stone Coal lies from 8 to 14 fathoms below the Beaumont Seam: it is variable in thickness, and has (excepting when in contiguity with the seam below) been little worked.

Its depth from the surface is as follows:—

COLLIERY.	FATHS.
Towneley	63
Blaydon Main	45
Garesfield	20

The following is a section of the Stone Coal Seam at Towneley Colliery:—

	FT.	IN.
Coal	2	8
Band	0	3
Coal	0	5
	3	4

SECTION AT BLAYDON MAIN COLLIERY.

	FT.	IN.
Coarse Coal	0	1
Coal	2	3½
Sagre Clay	0	3
Coal	0	4
	2	11½

SECTION AT GARESFIELD COLLIERY.

	FT.	IN.
Coal	2	5
Band	0	0½
Coal	0	6½
	3	0

The above, however, are favourable sections.

This seam is unworkable in the Auckland district: it makes good coke.

9.—Immediately below the Stone Coal at Garesfield, but from one to two fathoms below it at Blaydon Main, and five fathoms below it at Towneley, is the Lower Five-Quarter Seam, which presents the following sections:—

SECTION AT WYLAM COLLIERY.

	FT.	IN.
Splint Coal	0	5½
Coal	2	11½
	3	5

SECTION AT GARESFIELD COLLIERY.

	FT.	IN.
Coal	3	9

SECTION AT BLAYDON MAIN COLLIERY.

	FT.	IN.
Coal	0	10¾
Band	0	4¼
Coal	2	5
	3	8

SECTION AT TOWNELEY COLLIERY.

	FT.	IN.
Coal	0	8
Band	0	3
Coal	2	10
	3	9

This seam produces coals of pretty good quality, but is tender, and not well adapted for purposes of export where large coals are required. It is a good manufacturing coal, and by reason of its freedom from pyrites, is suitable for smiths' purposes. It makes excellent coke, the quality of which is still further improved by an admixture with the Five-Quarter coal, of coal from the Stone Coal Seam.

The Stone Coal and Lower Five-Quarter Seams form the Bustybank Seam of the Marley Hill and Pontop district. According to Mr. Buddle's synopsis, the Beaumont and Bustybank Seams are identified with each other: the present opinion is as above stated.

The section of the Bustybank Seam at Marley Hill Colliery, where it lies 40 fathoms below the Main Coal (Tyne Low Main), is as follows:—

	FT.	IN.
Coal	2	8
Band	0	4
Coal	0	6
Band	0	1
Coal	1	9
	5	4

SECTION AT MEDOMSLEY COLLIERY.

	FT.	IN.
Coal	3	2
Sagre Clay	1	9
Coal	3	11
	8	10

SECTION AT BERRY EDGE, NEAR SHOTLEY BRIDGE.

	FT.	IN.
Coal	1	10
Band	0	2
Coal	2	2
	4	2

Towards Hamsterley and Ebchester the Stone Coal and Five-Quarter Seams are again separated a few fathoms, and are worked separately under the names of the Upper and Lower Bustybank Seams.

The Bustybank Seam has been proved in a good state at Pelton Colliery, which is its most easterly point of exploration in the coal field. The section here is—

	FT.	IN.
Coal	2	6
Band	0	2
Coal	2	6
	5	2

It lies $38\frac{1}{2}$ fathoms below the Tyne Low Main Seam, called at Pelton, the Hutton Seam.

10.—The Three-Quarter Coal Seam at Towneley, corresponding to the Six-Quarter Seam at Wylam and the Main Coal at Walbottle Collieries, is the next seam, which has as yet proved workable in this district only. It lies from 3 to 6 fathoms below the Five-Quarter Seam.

At Wylam, the section is as follows:—

	FT.	IN.
Coal	4	0
Splint	0	$2\frac{1}{2}$
Coal	0	$4\frac{1}{2}$
	4	7

SECTION AT WALBOTTLE.

	FT.	IN.
Coal	3	1

11.—The at present supposed lowest workable seam found in the coal field of Northumberland and Durham is called the Brockwell Seam at Towneley, the Horsley Wood Seam at Wylam, the Splint Seam at Walbottle, and the Brockwell, Bitchburn, or Lower Main Coal in the Auckland and Etherley district.

It is found at the depth of from 30 to 45 fathoms below the Beaumont or Auckland Yard Coal Seam, and at the following depths from the surface:—

COLLIERY.	FATHOMS.
Towneley	83
Wylam	41
St. Helen's Auckland	79
Blackboy	156
Cockfield Fell	23

SECTION AT TOWNELEY COLLIERY.

	FT.	IN.
Coal	0	1
Jet	0	3
Coal	2	11
	3	3

SECTION AT WYLAM COLLIERY.

	FT.	IN.
Jet	0	2
Coal	2	3
Splint Coal	0	7½
	3	0½

The following is a section of the seam at St. Helen's (Auckland) Colliery :—

	FT.	IN.
Coal	0	11
Band	0	1½
Coal	1	4
Splint	0	2
Coal	3	1
	5	7½

The band of 1½ inch beneath the top coal thickens to the north and east, and to the west disappears altogether. At the adjoining colliery of Woodhouse Close, the following is a section of the seam near St. Helen's Colliery boundary :—

	FT.	IN.
Coal	1	3
Sagre Clay	0	8
Jet	0	0½
Coal	1	0¾
Splint	0	3¼
Coal	3	4¾
	6	8¼

Further to the north-east, at the Woodhouse Close Colliery shaft, which is about half-a-mile from the St. Helen's boundary, the band has increased to 35½ feet, and the coal under the band, which is 4 feet 8 inches thick, is the working seam of the colliery. The top coal, however, is worked, being taken down after the ground coal has been excavated, when the thickness of the sagre clay does not exceed one foot.

At Woodifield Colliery,[1] near the village of Crook, the seam presents the following section :—

	FT.	IN.
Coal	3	0
Band	1	0
Coal	4	2
	8	2

And at the collieries north and east the ground coal only is worked at present,

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[1] I am not quite sure whether the Woodifield Seam is really the Brockwell or the Bustybank Seam (Stone Coal and Lower Five-Quarter Seams). I am rather inclined to believe the latter. If this be the case, it then becomes a matter for speculation whether the Bitchburn and Bustybank Seams, or the Bitchburn and Brockwell Seams, are identical.

being generally of the thickness of 4 feet, or 4 feet 2 inches, the top coal having been separated from it by the thickening of the band.

The Brockwell Seam is generally rather tender, but of good quality, and an excellent coking coal. It produces[1] a second-rate household coal when in its best state, but it more generally occupies an inferior position in the market. Its great redeeming properties are the cheapness with which it can be worked, and the excellence of the coke manufactured from it.

Much doubt has prevailed as to the proper position in the coal series of the Bitchburn Seam. In the year 1846, however, a boring (and subsequently the sinking of the pits) at Blackboy Colliery, from the thill of the Main Coal, has almost set the matter at rest, the only question remaining being whether the Bitchburn Seam is the Bustybank or the Brockwell Seam, or a seam as yet unproved excepting in the Auckland districts. This point must remain undecided until further explorings are made between the Pontop and Auckland districts.

I have intentionally forborn to make any remarks upon the Byers Green and Whitworth Seam, as its connection with others is not completely traced. This seam may be the Beaumont or Harvey Seam. Mr. J. J. Atkinson, H.M. Inspector of Coal Mines, is of opinion that it is identical with the lower part of the Woodhouse Close Bitchburn Seam, having arrived at this conclusion from sections and levellings from Coxhoe Colliery to Woodhouse Close Colliery.

The position of the seams of coal worked at Radcliffe Colliery, near Warkworth, is also, in the opinion of many, not satisfactorily established. At this colliery, we have in the depth of 73 fathoms fifteen beds of coal, from 3 inches to 5 feet 4 inches in thickness, and in the aggregate 31 feet 1½ inch, equal to 7·10 per cent. These coals are of steam coal quality, resembling those of the Hartley and Cramlington districts.

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(1) The following is an extract from a letter written in the year 1818, by the late Mr. George Dixon, of Bishop Auckland, to the chairman of the committee of subscribers to the projected canal from the river Tees to West Auckland :—

"A fire was made of an unheaped peck of coals (the produce of the best colliery on the river Tyne, which, for obvious reasons, I do not name—suffice it, they stand at 34s. in the price list) weighing 19½lbs., and continued to burn from half-past six to eleven o'clock, or 4½ hours. In 2¾ hours all were burnt to a cinder. Next morning there remained only 5 ounces of ashes and 2¾lbs. of cinders, being too small a quantity to make another fire.

"A fire was next made of an unheaped peck of the Auckland Greenfield coals, weighing nearly 20lbs., and broken to the same size as the last. They continued to burn, in the same fireplace and *conducted in the same manner*, 5½ hours, being an hour longer than the other. Did not all burn to a cinder till 3¾ hours after the fire had been lighted, also an hour longer than before. Next morning there remained 5 ounces of ashes, and an unheaped peck of cinders, weighing 7½lbs. (being thrice the quantity which remained in the former experiment). Of these cinders a fire was made, and continued to burn an hour and forty minutes, which, added to the hour in the first fire, proves them to be more durable in consumption by two hours and forty minutes than the same quantity of the best coals from the Tyne.

"In both cases the fires burnt clear and pleasantly, and were only stirred or put together twice during the periods mentioned.

"The Tyne coal burnt more briskly than the other, but did not form its cinders or coke large; what remained of the former were very small.

"A similar experiment has been made with the Ramshaw coals, which gave nearly as favourable a result as the one above cited."

Plate 19 is a section of the strata sunk through at Norwood Colliery, near Gateshead, from the surface to the Beaumont Seam. The sinking through the clay and sand was attended with considerable difficulty, and forms a good illustration of the manner of passing through such deposits. I will, therefore, at a future period revert to it.

In this section there are seven seams of coal, of the aggregate thickness of 5 feet 10 inches, or 3·91 per cent. of the coal strata.

The deposit of clay has already been alluded to, and the three sections (Plate 20, Figs. 1, 2, and 3) show the position of the strata previous and subsequent to the deposit being made.

We must (having the Hutton Seam of coal in the positions "a" and "b") conclude that it was formerly continuous, as shewn in Fig. 1.

The fact of there being an alluvial deposit in the position shewn in Fig. 3, implies an intermediate state when a ravine existed, as in Fig. 2.

The pit referred to is situated within this fresh water deposit, or "Wash," as it is locally named, which is here 17 fathoms in thickness, the Hutton Seam, as seen in Fig. 3, being completely denuded.

The Beaumont Seam, of which a section is given (Fig. 4), is also much distorted at the shaft, probably owing to the influence of the same causes which occasioned the 15 feet upcast slip to the east, seen in Fig. 3, but it rapidly acquires a good section, being within a dozen yards of the thickness of nearly 4 feet, with 3 or 4 inches of band.

The following are analyses of the various descriptions of coal :—

DESCRIPTION OF COAL.	LOCALITY.	CARBON.	HYDROGEN, AZOTE, AND OXYGEN.	ASHES.
Splint	Wylam	74·823	11·265	13·912
	Glasgow ...	82·924	15·948	1·128
Cannel	Lancashire ...	83·753	13·699	2·548
	Edinburgh ...	67·597	17·837	14·566
Cherry	Newcastle ...	84·846	13·478	1·676
	Glasgow ...	81·204	17·375	1·421
Caking	Newcastle ...	87·982	10·665	1·393
	Durham ...	83·274	14·207	2·519
Anthracitic	Aberdare ...	89·290	8·565	2·145
	Neath	92·883	5·453	1·664

The variation in the quality of the seams of coal of the Newcastle coal field has been adverted to; but what renders the fact more remarkable is that, generally, the quality of the whole of the seams of coal in each district bears more or less the same character. I do not mean to state this is an invariable occurrence, but as examples I may adduce the Cramlington district, where the whole of the seams are very hard, free, and open burning, making much white ash, and suitable for steam purposes; the Heworth district, where the same seams are friable and tender, and adapted for the manufacture of gas, but not suitable for the purposes first named; the Tanfield

and Crook districts, where with even a less degree of hardness than the last, a greater purity is combined, and consequently a better adaptation to manufacturing and coking purposes; the Hetton and Blackboy districts, where the same seams afford coal of the finest household quality, and almost as hard as the produce of the Cramlington district. The variety of quality in different seams may not appear so very surprising, but that the same seam in different localities (not very far removed from each other), notwithstanding that it must have all been deposited uniformly, should vary so remarkably, is a curious subject for speculation; and it is no less so, that although the different seams may have been deposited at different, and in some instances widely different epochs, the same character should, to a certain extent, pervade the seams of an entire district, as mentioned above.

It would seem that the quality of coal is dependent less upon its original formation than upon the processes to which it has been subjected by the various revolutions which the earth has subsequently undergone. It would certainly appear that the agency of heat has been exerted upon coal since it was originally formed, and to this cause it seems proper to attribute many of the phenomena in which the seams of coal abound. How otherwise are we to account for the peculiar crystalline form of coal: or for the state in which we find it to contain fire-damp—or for crystallized pyrites? All these may be accounted for by the supposition of heat under pressure—air, of course, excluded.

The following is the composition of coals from the same seam in different localities:—

	CARBON.	HYDROGEN, OXYGEN, AND AZOTE.	ASHES.	WEIGHT OF A CUBIC FOOT IN LBS.
Steam Coal	80·750	15·400	3·850	77·11
Coking Coal	85·580	12·280	2·140	78·86
Household Coal	83·274	14·207	2·519	80·23

The coal measures of the Newcastle coal field also contain, although in small quantities, cannel coal, similar to that found so abundantly in the Lancashire and Scotch coal fields.

The following table shows the quantity of gas contained in the various coals, the comparative durability of flame, and the comparative illuminating power, from which is deduced the comparative value of the coals, given in the last column. It is taken from a table by Dr. Fyfe, of Aberdeen, inserted in Drs. Ronald and Richardson's Chemical Technology, page 579:—

COALS.	CUBIC FEET OF GAS PER TON.	COMPARATIVE DURABILITY OF FLAME.	COMPARATIVE ILLUMINATING POWER.	COMPARATIVE VALUE OF COALS.
Pelton	9,746	50·66	3·125	1·00
Ramsay's Cannel	9,692	60·66	3·33	1·27
Wigan do.	12,010	52·08	3·04	1·23
Donibristle do.	9,923	51·08	7·51	2·47
Lismahago do.	10,176	60·00	8·77	3·47
Capeldrae I. do.	11,500	65·41	8·312	4·05
Do. II. do.	9,670	73·61	10·10	4·62
Boghead	15,426	84·73	10·38	8·79

The Boghead Cannel or Torbane Hill Mineral occurs at Bathgate, in Linlithgowshire. The seam is very irregular in thickness, varying from 1 inch to 20 inches: it does not exist over a very large area. It extends as far north as Colinshields, as far east as Bathgate, and as far south as Torbane Hill, and on the west it has not been discovered beyond Armadale; and the district containing it is much troubled with faults. The upper part of the seam is brown, and the lower of a black colour. Its specific gravity varies from 1·1550 to 1·2185 (Dr. Penny). When distilled at a low red heat it gives off from 50 to 70 gallons of paraffin oil per ton of mineral. ("Coal and Ironstone of the West of Scotland," by Mr. Wm. Moore.)

Universally throughout the coal measures, beds and nodules of clay ironstone are found and worked. In the North Staffordshire coal field the ironstone beds are largely developed, the ore in that district consisting chiefly of a species of blackband.

The following is a section of the ironstone and coal measures of North Staffordshire. (Published section by Mr. J. C. Homer):—

No. of seams of ironstone.	Thickness of seams of ironstone.		No. of seams of coal.	Thickness of seams of coal.		Coal Measures.	Fathoms.	Feet.	Inches.	Fathoms.	Feet.	Inches.
	Ft.	In.		Ft.	In.							
1	1	6				Blackband ironstone or half yards ...	0	1	6			
						Marl and bass...	6	0	0			
2	4	0				Red shag ironstone	0	4	0			
			1	1	9	Coal	0	1	9	7	1	3
						Marl and bass...	11	5	6			
3	2	3				Red mine ironstone	0	2	3			
			2	2	0	Coal	0	2	0	12	3	9
						Marl, coal, and bass	5	5	9			
			3	1	8	Coal	0	1	8	6	1	5
						Binds, coal, and bass	10	2	6			
			4	1	0	Coal	0	1	0	10	3	6
						Rock, binds, and bass	12	5	0			
			5	0	9	Coal	0	0	9	12	5	9
						Marl, warrant, and rock	13	0	0			
4	4	0				Bassy mine ironstone...	0	4	0			
			6	2	0	Coal	0	2	0	14	0	0
						Warrant	2	3	0			
			7	2	2	Little Row coal	0	2	2	2	5	2
						Marl and bass...	3	0	0			
			8	5	8	Peacock coal	0	5	8	3	5	8
						Metal and bass	6	4	6			
			9	4	0	Spencroft coal...	0	4	0	7	2	6
	11	9		21	0	*Carried forward*				77	5	0

No. of seams of ironstone.	Thickness of seams of ironstone. Ft.	In.	No. of seams of coal.	Thickness of seams of coal. Ft.	In.	COAL MEASURES.	Fathoms.	Feet.	Inches.	Fathoms.	Feet.	Inches.
	11	9		21	0	*Brought forward*	...	...	...	77	5	[illegible]
						Warrant and metal	8	5	6			
5	6	0				Gubbin ironstone in bands	1	0	0	9	5	6
						Binds	5	5	5			
			10	9	0	Great Row coal	1	3	0	7	2	5
						Binds, rock, metal, and bass	13	0	9			
			11	6	6	Cannel Row coal	1	0	6	14	0	3
						Marl, coal, metal, binds, and bass ...	16	3	0			
			12	1	0	Wood mine coal	0	1	0	16	4	0
						Bass	2	0	0			
6	2	0				Pennystone ironstone...	0	2	0			
						Bass	2	0	0			
7	0	10				Deep mine ironstone	0	0	10			
			13	3	0	Coal	0	3	0	4	5	10
						Warrant, metal, binds, and bass ...	11	3	0			
8	1	3				Chalky mine ironstone	0	1	3			
			14	1	4	Coal	0	1	4	11	5	7
						Warrant	2	0	0			
9	0	8				Brown mine ironstone	0	0	8			
			15	1	0	Coal	0	1	0	2	1	8
						Marl, coal, and bands of ironstone ...	9	5	4			
			16	3	1	Bungilow coal	0	3	1	10	2	5
						Marl, binds, rock, and metal	18	0	5			
			17	1	0	Coal	0	1	0	18	1	5
						Marl, binds, rock, and bass	16	1	5			
			18	2	2	Little coal	0	2	2	16	3	7
						Bass	2	1	0			
			19	5	0	Winghay or Knowl's coal	0	5	0	3	0	0
						Metal, bass, and metal	5	5	6			
10	1	5				Winghay or Rusty mine ironstone ...	0	1	5			
						Binds, metal, ironstone, and bass ...	19	1	8			
11	0	6				Billy mine ironstone	0	0	6			
			20	1	6	Coal	0	1	6	25	4	7
						Strong bands, coal, metal, and bass ...	20	5	4			
			21	1	6	Coal	0	1	6	21	0	10
						Rock metal and binds	5	4	6			
			22	2	9	Four-feet coal...	0	2	9	6	1	3
						Clay, bass, and metal...	8	2	0			
			23	11	6	Rowhurst or Ash coal	1	5	6	10	1	6
	24	5		71	4	*Carried forward*	...	...	...	256	3	10

NO. OF SEAMS OF IRONSTONE.	THICKNESS OF SEAMS OF IRONSTONE.		NO. OF SEAMS OF COAL.	THICKNESS OF SEAMS OF COAL.		COAL MEASURES.	FATHOMS.	FEET.	INCHES.	FATHOMS.	FEET.	INCHES.
	Ft.	*In.*		*Ft.*	*In.*							
	24	5		71	4	*Brought forward*	...	...	...	256	3	10
						Marl, metal, rock, coal, and bass ...	13	3	3			
12	1	0				Burnwood ironstone	0	1	0			
			24	5	3	Burnwood coal	0	5	3	14	3	6
	25	5		76	7	(*The bottom of the Coal and Ironstone Series.*)				271	1	4
						Fireclay, rock, metal, and bass ...	9	0	0			
			25	3	6	Twist coal and cannel	0	3	6	9	3	6
						Grey metal and black bass	9	5	0			
			26	1	6	Coal	0	1	6	10	0	6
						Dark metal, grey metal, bass, and metal	26	1	0			
						Red rock, black metal, grey rock, bass, and metal	19	0	0			
			27	1	0	Coal	0	1	0	45	2	0
						Grey metal, rock, metal and rock binds	15	0	7			
						Binds, metal and black bass	14	5	0			
			28	5	3	Birchenwood coal	0	5	3	30	4	10
						Rock, grey metal, and bass	10	5	6			
			29	4	0	Mossfield or Easling coal	0	4	0	11	3	6
						Dark metal	5	4	6			
			30	2	3	Coal	0	2	3	6	0	9
						Metal, grey rock, and bass	21	5	0			
			31	3	6	Yard coal	0	3	6	22	2	6
						Binds	5	1	4			
			32	4	6	Ragman or Birches coal	0	4	6	5	5	10
						Metal, rock, and bass	13	1	0			
			33	4	3	Rough seven feet or Whitfield coal ...	0	4	3	13	5	3
						Warrant coal, metal, rock, and bass...	20	4	8			
			34	4	0	Stony eight feet or Bellringers' coal...	0	4	0	21	2	8
						Binds, rock, and shaly bass	20	0	0			
			35	7	0	Ten feet coal	1	1	0	21	1	0
						Grey marl, metal, and rock	21	5	0			
			36	4	6	Bowling Alley or Magpie coal ...	0	4	6	22	3	6
						Blue metal, coal, and metal	12	3	0			
			37	5	0	Holly Lane coal	0	5	0	13	2	0
						Warrant, grey rock, and metal ...	19	3	0			
			38	5	0	Sparrow Butts coal	0	5	0	20	2	0
	25	5		131	10	*Carried forward*	...	...	...	525	5	2

NO. OF SEAMS OF IRONSTONE.	THICKNESS OF SEAMS OF IRONSTONE.		NO. OF SEAMS OF COAL.	THICKNESS OF SEAMS OF COAL.		COAL MEASURES.	FATHOMS.	FEET.	INCHES.	FATHOMS.	FEET.	INCHES.
	Ft.	*In.*		*Ft.*	*In.*							
	25	5		131	10	*Brought forward*	...	...	...	525	5	2
						Warrant, metal, rock, and binds ...	12	5	0			
			39	2	6	Ironstone coal	0	2	6			
										13	1	6
						Blue metal, rock, and metal	11	1	6			
						Bass, ironstone, and metal	10	0	0			
			40	2	0	Coal	0	2	0			
										21	3	6
						Binds and rock roof	18	3	0			
			41	7	0	Seven feet Nabbs, Seven feet Banbury, or Frog Row coal...	1	1	0			
										19	4	0
						Warrant, clod, and rock	6	2	6			
						Light metal, bass, and rock	10	0	0			
						Clod, ironstone, and bass	12	4	6			
			42	8	6	Eight feet Nabbs, Eight feet Banbury, or Cock's-head coal	1	2	6			
										30	3	6
						Bass, marl, rock, binds, and bass ...	13	4	6			
						Coal and bass	12	3	0			
						Rock and bass	10	0	0			
			43	9	0	Bullhurst coal	1	3	0			
										37	4	6
						Metal and bass	9	0	0			
			44	3	0	Winpenny coal	0	3	0			
										9	3	0
	25	5		163	10					658	1	2

The above section shows the coal measures of North Staffordshire, from the highest seam of ironstone to the lowest workable seam of coal, to be of the thickness of 658 fathoms, 1 foot 2 inches, or 3,951 feet, divided into three distinctly marked series, the peculiarities and thicknesses of which are as follows :—

	FEET.
Upper series, which may be called the 'Coal and Ironstone' series, contained between the roof of the Blackband ironstone, No. 1, and the floor of the Burnwood coal, No. 24. It contains 12 beds of ironstone of the united thickness of 25 feet 5 inches, or 1·56 per cent., and 24 beds of coal of the united thickness of 76 feet 7 inches, or 4·69 per cent....	1,627
Middle or barren series, contained between the floor of the Burnwood coal and the roof of the Birchenwood coal. It contains 3 seams of coal of the united thickness of 6 feet, or 1·05 per cent.	569½
Lower series, which may be called the Coal series, contained between the Birchenwood coal and the floor of the Winpenny coal. It contains 17 seams of coal of the united thickness of 81 feet 3 inches, or 4·61 per cent....	1,755½
	3,951

The North Staffordshire iron ores present the following analyses. (Memoirs of Geological Survey: Iron Ores of Great Britain, p.p. 279, &c.) :—

	RED SHAG.	RED MINE.	BASSY MINE.	CANNEL MINE.	PENNY-STONE.	DEEP MINE.	CHALKY MINE.
Protoxide of Iron	46·53	50·73	45·53	41·80	46·35	48·33	51·07
Peroxide of Iron	...	0·45	5·00	...	3·00	...	...
Protoxide of Manganese...	2·54	1·86	1·74	2·16	1·61	2·99	2·36
Alumina	0·97	0·26	0·32	0·53	0·30	0·41	0·54
Lime	2·41	2·52	2·91	5·07	1·93	1·52	1·74
Magnesia...	1·39	1·26	2·13	3·03	2·24	1·19	1·10
Carbonic acid	30·77	33·89	32·12	32·40	32·46	32·76	33·63
Phosphoric acid	0·69	0·73	0·86	1·40	0·67	0·87	1·12
Sulphuric acid	0·04	0·08	0·08	trace.	trace.	trace.	trace.
Bisulphide of Iron	0·34	0·30	0·37	0·04	0·15	0·19	0·17
Water, hygroscopic...	1·47	Undet[d].	2·29	0·36	1·43	0·85	0·99
Water, combined				0·71			
Organic matter	10·46	6·41	5·20	0·79	2·95	1·17	1·24
Ignited insoluble residue	2·27	0·72	1·95	10·81	7·29	9·28	5·18
	99·88	99·21	100·50	99·10	100·38	99·56	99 14
Metallic Iron	36·39	39·84	39·13	32·64	38·29	37·83	39·88
Insoluble residue	...	...	...	..	...	...	...
Silica	1·93	0·38	1·36	7·32	5·78	6·25	3·02
Alumina	0·25	0·32	0·42	3·28	1·22	2·41	1·93
Peroxide of Iron	0·05	...	0·06	0·20	0·11	0·21	0·12
Lime, Potash, &c.	0·23	0·17	0·05	0·13	0·18	0·22	0·28
	2·46	0·87	1·89	10·93	7·29	9·09	5·35
	J. SPILLER.	A. DICK.	A. DICK.	J. SPILLER.	A. DICK.	A. DICK.	A. DICK.

In the North of England, as well as in most other districts, as we proceed downwards in the lower part of the coal measures, we find the beds of coal thinner and more distant from each other, and eventually we meet with a succession of coarse sandstones and grits, constituting the series called the (*c*) *Millstone Grit.* This series probably attains its greatest development in this country in Lancashire. It produces excellent building and flag stone, and a few thin seams of coal.

(*c*)—*The Mountain Limestone.*

On referring to the geological map, we observe that the Mountain Limestone is widely distributed; and it must in fact (for its general value) be considered one of the most important formations, economically considered, that we possess.

In the upper formations we find chalk, and from it we obtain lime and building stone.

Further down, coal in small quantities, building stone, ironstone, alum, and salt; further down, coal and ironstone.

In the Mountain Limestone we have coal, ironstone, lime, building stone, lead, and copper; the whole in abundance.

There is much difference in the character of the Mountain Limestone series in different localities, and in no two districts is there a greater difference than between those of Somersetshire and Northumberland. In the former, the series consists of beds of limestone, of various shades of colour, from light to dark grey, and of different degrees of fineness of grain. At Cheddar, the thickness of the limestone cannot be less than 600 yards.

The limestone contains some beds of chert of insignificant thickness, and is occasionally traversed by fissures containing brown hæmatite and sulphuret of lead.

In Northumberland, however, so far from forming the bulk of the carboniferous limestone strata, the limestone only occupies a minor position. Mr. Boyd, in a paper read to the North of England Institute of Mining Engineers (Transactions, vol. 9, p. 202), records the following as being the proportion of limestone and coal found in an aggregate thickness of 606 fathoms 5 feet:—

	Feet.	Per cent.
Limestone ...	277½	8·48
Coal	90	2·48
Other strata (shales and sandstones)	3,273½	89·04
	3,641	100·00

The Mountain Limestone of Northumberland rises from beneath the millstone grit about 7 or 8 miles west of Newcastle, and near the River Coquet on the north. It is first seen on the sea coast, a little to the north of Boulmer, and is found in the cliffs as far as Berwick-upon-Tweed.

The whole of the seams of coal of the Berwick coal field, and all of those worked in the north and north-west parts of Northumberland, belong to the Mountain Limestone measures. The quality of these seams is not generally so good as that of the seams belonging to the coal measures. That of the Main Coal at Shilbottle, near Alnwick, is of a peculiar character; the coal being exceedingly durable, and the ash of a dark brown or rather purple colour, and very heavy. This coal is very hard.

Plate 21 is a section of the strata at the Shilbottle old colliery, from which it appears that there are beneath the clay 331 feet of strata to the bottom of the Shilbottle Main Coal Seam, containing 7 seams of coal of the aggregate thickness of 10 feet 9 inches, equal to 3·25 per cent., and 4 beds of limestone of the aggregate thickness of 50 feet, or 15·1 per cent.

This section is in the upper part of the series: the Scremerston coal field, near Berwick, is situated in the lower part, and beneath the principal limestone beds.

The following table shows the position of the Scremerston Limestones as they appear upon the sea shore :—

BENEATH EACH OTHER.	NAME OF LIMESTONE.	THICKNESS.
0 Fathoms.	Dryburn	20 Feet.
40 „	Saltpanho South Quarry	11 „
20 „	Lincoln-lee, found at Barrington	22 „
20 „	Saltpanho (18 feet good)	24 „
20 „	Detchen Grey Mare	6 „
6 „	Dun Stone, inferior	5 „
50 „	Oxford	17 „
60 „	Wood End	10 „
30 „	Dun Stone, inferior	6 „
246 Fathoms.		121 Feet.

A seam of coal 2 feet thick is found between the Saltpanho and Lincoln-lee limestones, and the next coal of any value is found about 6 fathoms beneath the Oxford limestone.

1.—This seam is called the Greenses or Allerton Coal: it is 30 inches thick, and has been wrought many years on the Greenses and Allerton estates.

2.—The Muckle Howgate Coal, generally about 3 feet thick, has a bandy roof, and is a leafy coal with a blue metal floor. It is said to be 40 fathoms above the Wood End Quarry, and is seen on the road from Allerton Stead, and also near and on the east side of Felkington Kiln, and again at Wood End. This seam has been worked within two hundred yards of the Scremerston New Winning (1840), near the turnpike road, about three miles from Berwick.

3.—The Little Howgate Seam, freestone band roof, coal 2 feet 2 inches, blue metal floor, lies about 4 fathoms above the Wood End Quarry, and was also found in Hogarth's East field, near to the Saltpanho Sea-houses.

4.—The Caldside or Fawcett Coal, limestone band roof, coal 3 feet 4 inches (sometimes, however, with a band of 16 or 18 inches, when the coal is greatly diminished in thickness), and, with a freestone floor, is supposed to be, on the Scremerston estate, 35 to 40 fathoms below the Little Howgate Seam, and consequently about 3 fathoms below the lowest bed of limestone or Dun stone mentioned above.

The Caldside level has been carried, and the coal wrought to the Unthank east boundary from the sea, a distance of nearly two miles. The seam has been found and wrought in the flat ground between the Longey-heugh and Berryhill Cuts, on the Etal estate, where it is called the Fawcett Coal. It is also worked near the Wood End quarry, and on the east side of Etal Moor (on the Barmoor estate), whence it takes its name; also on the east side of the Ford estate, and at Doddington, and Jackson's Colliery of Biteabouts: at these places it is about 22 inches thick.

5.—The Scremerston Main Coal and Unthank Main Coal, and at all other places named the Blackhill Seam, under which name its quality is inferior, has been worked at Scremerston and Unthank for considerably upwards of a century: wrought as the Blackhill Coal at Felkington; near the Whin Dike, Mattalees; near the Etal Plantation houses and on the moor adjoining; at Slainsfield and at the Blackhill in Ford Moss, whence it derives its name; and also on the Doddington estate. It lies about 55 fathoms below the Caldside Seam at Scremerston.

The section of the Scremerston Main Coal, at the Scremerston new pit, is—

	FT.	IN.
Top coal	2	10
Band	0	2
Ground coal	1	3
	4	3

At the Restoration Pit the section was—

	FT.	IN.
Top coal	2	5
Band	0	4
Ground coal	0	6
	3	3

Immediately over the coal is a bed of limestone 1 foot 2 inches thick, above which is a thin coal seam 7 inches thick.

6.—The Stony Coal, worked on the Scremerston estate within 80 yards of the Berwick Hill boundary, and on Unthank Common, is a very strong coal and works large. The section of this seam is as follows:—

	FT.	IN.	FT.	IN.
Roof freestone	4	0		
Dant, mixed with coal	0	4		
			4	4
Top coal	0	10		
Danty black stone	0	4		
Middle coal	1	3		
Black dant	0	2		
Coarse hard stone	0	11		
Coal	0	10		
			4	4

The coal being 2 feet 11 inches, but varying from 2 feet 9 inches to 3 feet 2 inches.

This seam has been tried and found in great perfection in the Scremerston Restoration Pit, but was barred up on account of its liability to spontaneous inflammation. It is $3\frac{1}{2}$ fathoms below the Main Coal.

7.—The Cancer Coal, of Berwick Hill, the Bulman Coal of Murton, and the Main Coal of Thornton, Shoreswood and Greenlaw Walls, Felkington, Etal, Longey-

heugh, and Slainsfield, is the thickest seam of the district, but has generally a bad roof, which requires the top coal to be left as its support. The section is as follows:—

	FT.	IN.
Soft metal roof, several feet thick.		
Top coal	1	8
Chalk stone	0	1
Fine splint coal	1	1
Rough coarse coal	0	6
Band	0	7
Good coal	1	0
Chalk stone	0	1
Bottom coal	0	9
	5	9

The coal being 5 feet, but varying from 3 feet 5 inches to 6 feet 9 inches.

	TOTAL THICKNESS.			THICKNESS OF COAL.	
	FT.	IN.		FT.	IN.
Murton	5	8	...	5	0
Gatherick	4	9	...	4	3
Ford	5	0	...	4	2
Felkington	6	2	...	5	5
Shoreswood	5	10½	...	4	9½

This seam is 17 fathoms below the Stony Coal.

8.—The Three-Quarter Coal is a good hard lumpy coal, and is worked at Berwick Hill, Murton, Thornton, Shoreswood, Felkington, and Ford Corner. The section is as follows:—

	FT.	IN.	FT.	IN.
Good blue metal roof			6	0
Top coal	1	1		
Black danty coal	0	4		
Coarse grey stone	0	8		
Bottom coal	1	1		
			3	2
Thill soft and dry.				

This seam lies about 18 fathoms below the Cancer Coal: it is expensive to work.

9.—The Cooper Eye Seam, formerly called the Stony Coal at several places, and anciently at Ford, the Lady Coal. The section is as follows:—

	FT.	IN.
Top coal	1	0
"Macker," which will burn, but leaves a "ghaist" or "skeleton" ...	0	3
Ground coal, coarse	1	4
	2	7

The coal being 2 feet 4 inches, but varying from 2 feet 2 inches to 2 feet 8 inches.

At Berwick Hill, it varies from 2½ feet to 4½ feet: at Shoreswood, from 1 foot 3 inches to 3 feet 4 inches.

This seam has been proved in all the districts, with the exception of Scremerston, but it probably exists there as well, as it has been worked at Berwick Hill, which adjoins on the rise: it lies probably 3 or 4 fathoms below the Three-Quarter Seam.

10.—The Wester Coal is the lowest seam that has been worked in this district. It varies in thickness from 3 feet to 4 feet 6 inches. It was anciently worked at some of the rise pits in Shoreswood, and was sunk to in the (1839) working pit, but from its inferior quality, it was not worked. It lies 13 fathoms below the Cooper Eye Seam.

The distance between two adjacent seams often materially varies in different parts of this, as well as other coal fields. Thus, the distance between the Cancer and Cooper Eye Seams is, at Ford, 17 fathoms; at the adjoining colliery of Etal, 23 fathoms; at Berwick Hill, 26 fathoms; and at Gatherick, 14½ fathoms. The direction of the dip varies considerably, but it always inclines more or less towards the east.

The following analyses of Mountain Limestone, by Mr. Hugh Taylor, are taken from the Proceedings of the North of England Institute of Mining Engineers, vol. iii., p. 24:—

	1	2	3	4
	Hobberlau, near Alnwick.	North Sunderland.	Holy Island.	Holy Island: Bottom Bed.
Carbonate of lime	96·986	96·637	59·280	96·234
Carbonate of magnesia	1·006	1·938	35·121	2·076
Peroxide of iron and alumina ...	0·590	0·526	3·746	0·242
Sand	1·209	0·707	1·384	1·273
	99·791	99·808	99·531	99·825

The large quantity of Carbonate of Magnesia in No. 3, is in striking contrast to the small quantity of this substance contained in the Magnesian Limestone of Raisby, of which an analysis was given in page 21.

Beds of ironstone, and veins of lead and copper ore of great value, are also frequent in the Mountain Limestone measures, but beneath them they are more rare; and coal, according to present observation, ceases to exist.

One of the principal causes of the advantages possessed by Great Britain in the manufacture of iron, has arisen from the number and variety of the beds of argillaceous and blackband ironstone, which, as has been already shown, alternate with the beds of coal, in most of its coal fields, and in consequence of which, the same localities, and in many instances the same mineral workings, frequently furnish both the ore and the fuel used in smelting it. This condition of things has, within the last few years, been considerably changed, owing to the large discoveries of ironstone or ore found in the upper formations as well as in the lower, where coal is as yet undiscovered. The

facilities given by railways, however, render of less consequence the space between the fuel and the ore; and the (in many instances) comparatively low cost of producing the ore from these formations, more than counterbalances the cost of carriage. In fact, notwithstanding this cost, we produce iron far more cheaply than we did; and we have, within the last fifteen years, doubled our make—the present production of iron being at the rate of 4,500,000 tons per annum.

The Mountain Limestones of Lancashire, Cumberland, Durham, Derbyshire, Gloucestershire, Somersetshire, and South Wales, all furnish important beds of ironstone and veins and beds of hæmatite. Those of Ulverstone, Whitehaven, and the Forest of Dean, are most extensively worked, and will, for many years, yield large supplies. The brown Hæmatite and white Carbonates of Iron, of Aldstone Moor, Weardale, and the Brendon Hills, also exist in large masses, and are of great importance. In the older rocks of Devonshire and Cornwall are found many considerable veins of black hæmatite, and in the Granite of Dartmoor, numerous veins of magnetic-oxide of iron and specular iron ore. And these, with the immense deposits of Cleveland, Lincolnshire, Northamptonshire, Oxfordshire, Wiltshire, and Sussex, furnish us with supplies of various iron ores which may be said to be practically inexhaustible.

The brown hæmatites deserve especial attention: they are found associated in very large masses with the lead veins, and occasionally they occur as regular beds. They contain from 20 to 40 per cent. of iron.

The following is an analysis of Weardale ore of this description, by Mr. Spiller (Government School of Mines): see Memoirs:—

Peroxide of iron	49·50
Protoxide of iron	10·77
Protoxide of manganese	3·06
Alumina	0·43
Lime	5·68
Magnesia	1·20
Silica	0·29
Carbonic acid	14·49
Phosphoric acid	0·01
Sulphuric acid	trace.
Bisulphide of iron	0·03
Water, hygroscopic	1·81
Do., in combination	6·63
Organic matter	trace.
Insoluble matter, chiefly silica	6·90
	100·80
Metallic iron	38·56

Sometimes these ores exist as riders to a vein: sometimes they form its entire mass, and in this case they occasionally attain a thickness of 20, 30, or even 50 yards. Remarkable changes sometimes occur in the character of metalliferous veins: the same vein which, at one point, bears principally lead or other ore, changing at another into a calamine vein, and then again into brown hæmatite. The character of the hæmatites seems to change somewhat with the depth; and it is very usual to find that hydrated peroxides, found near to the surface, in the Lias and Greensand, &c., approach carbonates when covered by a sufficient thickness of stratification.

The red hæmatites of Cumberland and Lancashire are in quality, perhaps, the finest in the kingdom: they contain from 60 to 65 per cent. of iron. They are found both as veins traversing the Mountain Limestone, transversely to the planes of stratification, and also as beds more or less regular. The former appears to be the general character (though not invariably so) of the Ulverstone and Furness ores; whilst at Whitehaven, there are two, if not more beds of irregular thickness, but with clearly defined roofs and floors, and often divided themselves by regular partings.

These beds attain a considerable thickness, occasionally 20 or 30 feet, or more. The area over which they extend is not yet well known, but they have been worked extensively for many years, and their workings are rapidly extending, and the quantity extracted from them is increasing in proportion.

The following is the average analysis of the Cleator Moor, Gilbrow, and Lindale Moor Hæmatites, by Messrs. Dick and Spiller, of the Government School of Mines: see Memoirs :—

Peroxide of iron	90·36
Protoxide of manganese	0·18
Alumina	0·29
Lime	1·18
Magnesia	0·51
Carbonic acid	0·98
Phosphoric acid	trace.
Sulphuric acid	0·06
Bisulphide of iron	0·06
Water, hygroscopic	0·13
Do. combined	0·06
Insoluble residue, chiefly silica	6·76
	100·57
Metallic iron	63·26

The hæmatitic iron ore, of the Forest of Dean, lies in the Mountain Limestone; a smaller deposit being found in the Millstone Grit; being, in each case, a sort of semi-stratum, consisting of a generally well defined compound of masses of ore called "churns," with strings or thin continuations of ore, and barren ground intervening

between them, the whole, in each case, occupying a tolerably regular position in the measures. This ore, particularly that found in the limestone, is a calcareous ore, varying greatly in richness, but remarkable for the excellent quality and strength of the iron which it produces, and for the improvement it effects in the working of blast furnaces, and in many cases in the iron, when mixed with other ores. It averages about 38 per cent. of iron.

The following is given as an average analysis, by Mr. Truran (Iron Manufacture of Great Britain) :—

Peroxide of iron	54·0
Carbonate of lime	35·0
Clay	7·0
Moisture	4·0
	100·0
Metallic iron	37·5

In a thickness of about 2,000 feet of the alternating beds of sandstone, shale, and limestone, which form the strata of the mining districts of Allendale, Aldstone, and Weardale, there is one single stratum of limestone, called the Great Limestone, the veins of which have produced nearly, if not quite as much lead ore, as all the other strata put together. Its thickness, which is tolerably uniform over several hundred square miles of country, is about 60 feet.

Plate 22 is a section of the strata at Cronkley, in the Manor of Lune, taken from a publication entitled "Geological Sections of Hudgill Burn, &c.," by Mr. Sopwith, and illustrates the process of lead mining very well.

The limestone, called here the Whin-top Limestone, corresponds to that named the Tyne-bottom Limestone in Forster's Section of the Strata from Newcastle-upon-Tyne, to the Mountain of Cross Fell in Cumberland, and is 68½ fathoms beneath the Great Limestone above named.

In illustration of the rich deposits of lead ore which have been found in the Great Limestone, may be mentioned the Rampgill vein, sometimes 12 feet wide of nearly solid ore, which has been known to yield from a single length (15 fathoms), at Coalcleugh, 4,000 tons of ore in the course of 12 years.

Lead ore is also found in other strata of the Mountain Limestone series, and this mass of strata is in consequence named the Lead Measures.

As seen in the section, there is a great bed of Basalt, locally named the Whin Sill, a rock of similar composition to Basaltic dikes, and also to the Trap rocks of the neighbourhood of Edinburgh, Glasgow, Dudley, Giant's Causeway, Staffa, &c.

The Whin Sill may be seen at the High Force in Teesdale, where it forms the barrier over which the river dashes. It also ranges across Northumberland in a north-easterly direction, where it is seen at various places, among which may be

mentioned Ratcheugh Crag, near Alnwick, the cliffs at Dunstanborough, and still further eastward in Holy Island.

A bed, termed Toad Stone, occurs in Derbyshire, which corresponds to the Whin Sill of the North of England. The actual distinction between the two has not been pointed out; and since their geological position is the same, they may probably be considered as identical.

The Whin Sill is a very hard stratum, of a dark greenish grey colour: emits fire with steel, and very rarely produces metallic ores. Several beds of shale, post, and limestone are found beneath the Whin Sill, among the rest the Great Rundle Beck, or Melmerby Scar Limestone, which is the thickest limestone in the Cumberland section, being 22 fathoms in thickness.

The most common ore of lead is Galena, or Sulphuret of Lead, which contains 80 to 85 per cent. of metallic lead: a cubic foot of pure Galena weighs about 7,000 ounces. The following are analyses of this substance. (Phillips' Mineralogy, p. 349):—

Lead	79·6	83·00	85·13
Sulphur	13·4	16·41	13·02
Silver	7·0	traces.	0·00
	100·0	99·41	98·15
	(Beudant).	(Westrumb).	(Thomson).

In Derbyshire the lead mines are also in the Mountain Limestone; they are supposed to have been worked in the time of the Romans: the Saxons and Danes were also engaged in working the mines of Derbyshire; and from that time, during the whole period of English history, these lead mines have been an object of attention. Lead is also found in Scotland, in the Lead Hills and at Wanlockhead; and considerable quantities are obtained from the Isle of Man, from North Wales, and from Somersetshire.

In France, in the Department of the Sambre and Meuse, lead ore is found in veins traversing limestone; and the limestone of Tarnowitz, in Silesia, also contains remarkable deposits of lead ore. The Mountain Limestone also contains veins of copper ore. In the northern counties, the principal metallic mines worked are for lead; but in Cumberland and other places there are many remains of old workings for copper.

Edward IV., in the eighth year of his reign, granted all his copper mines, containing gold and silver, in Cumberland, Westmorland, and Northumberland, to Dodrick Waverswick.

The old copper mine of Ecton, on the borders of Derbyshire, is also in the Mountain Limestone. This has been one of the most remarkable mines in the kingdom. It is situated in a dark brown stratified limestone, the beds of which are greatly deranged. The ore was deposited in a large accumulated mass, called by the

Germans "Stock-werk." It is supoosed that this mine was worked at a very early period: at one time about 1,000 persons were employed in the works, and then it afforded an immense produce of rich ore.

At Currie, about five miles west of Edinburgh, copper ore is also found: it is said to be deposited in limestone.

Ores of zinc are common in the Mountain Limestone, especially the Sulphuret or Zinc Blende, commonly called Black Jack. Calamine or Carbonate of Zinc is found in the Mendip Hills, near Shipham.

The organic remains of the Mountain Limestone are abundant. They consist largely of Corals and Crinoidea: there are also varieties of Productus, Spirifer, Terebratula, Goniatites, &c.

9.—Devonian Formation.—

a Conglomerate and Old Red Sandstone.
b Cornstone and Marl.
c Ledbury Shales.

This formation is of enormous thickness in Herefordshire, Worcestershire, Shropshire, and South Wales, where it is seen to crop out beneath the limestone (Carboniferous), and to repose upon the Silurian rocks. In that region its thickness has been estimated by Sir R. Murchison at 10,000 feet. It consists there of

a A quartzose conglomerate passing downwards into chocolate, red and green coloured sandstone, and marl: remains of fishes.

b Cornstone and marl (red and green argillaceous spotted marls, with irregular courses of impure concretionary limestone, mottled red and green: remains of fish).

c Ledbury shales (thin olive shales of Ledbury and Ludlow, and sandstones intercalated with thick beds of red marl: remains of mollusca and fishes).

By consulting geological maps, it will be perceived that from Devonshire to the north of Scotland, the Old Red Sandstone appears in patches and often in large tracts. Many remains of fish have been found in it in Caithness, and various organic remains in the northern part of Fifeshire, where it crops out from beneath the Carboniferous formation and spreads into the adjoining southern half of Forfarshire, forming, together with the Trap or Basalt, the Sidlaw Hills and Valley of Strathmore.

10.—Silurian Formation.—

	Feet.
a Upper Ludlow rock	
b Aymestry Limestone	2,000
c Lower Ludlow rock	
d Wenlock Limestone	3,000
e Wenlock Shale	
f Llandovery Shales and Slates	2,600
g Caradoc Limestone	12,000
h Llandeilo Flags	1,200

The characteristic fossils are marine mollusca, of almost every order, with Corals, Trilobites, &c.

The well-known Dudley Limestone, so rich in organic remains, belongs to the Wenlock division of the Silurian formation, which consists in its upper portion of limestone, more or less crystalline, and highly charged with Corals and Encrinites of species distinct from those of the Mountain Limestone. No land plants seem to have been discovered in strata which can be unequivocally demonstrated to belong to the Silurian period. At May Hill, however, in the uppermost part of the Downton Sandstone (formerly classed by Sir Roderic Murchison, under the name of "Tilestones," with the Devonian formation), and immediately beneath the lowest strata of the Old Red Sandstone, numerous small globular bodies have been found, which have been determined by Dr. Hooker to be the sporangia of a cryptogamic land plant. (Lyell, Elements, p. 548).

It is important that this barrenness of land plants should be remembered, as there is otherwise a considerable resemblance between some of the Silurian shales and some of those belonging to the coal measures, a resemblance which has, occasionally, led to grave error. In the limestones of Lake Michigan, in North America, and in other regions bordering the great Canadian lakes, Chain Corals and Trilobites are also found, and from their fossils generally, they seem to belong to the Silurian period. It is necessary to bear this in mind, because there is little doubt that the rapid progress continually being made in America will, in all probability, induce great research into the mineral resources of that country; and as we have already seen how error has been fallen into, by ignorance of the Silurian rocks, and particularly of the true nature of the Silurian shales, the subject is certainly well worth attention.

The copper mines, formerly worked near Keswick, were in veins traversing the lower Silurian rocks. Dr. Fuller, in his "Worthies of Cumberland," observes "that in taking the rich copper mines from the Duke of Northumberland at Keswick, it came to pass that this queen (Elizabeth) left more brass than she found iron ordnance in the kingdom;" and in the tenth year of her reign, Plowden says, "she took from the Earl of Northumberland his rich copper mine of Keswick, because of its holding so much silver and gold in the ore."*

* According to the law of England, the only mines which are termed royal, and which are the exclusive property of the Crown, are mines of silver and gold. This property is so peculiarly a branch of the royal prerogative, that it has been said, that though the king grant lands, in which mines are, and all mines in them, yet royal mines will not pass by so general a description. (Bainbridge, Law of Mines and Minerals, 2nd edition, p. 46.) This right was considered to exist in respect of the excellency of the thing: that the common law appropriated everything to the persons whom it best suits, as common and trivial things to the common people; and because gold and silver were most excellent things, the law had appointed them to the person who is most excellent, and that was the king. Plowden himself propounds an alchemical theory on the origin and transmutation of all metals, which was, no doubt, designed to throw light upon the subject, but which, it must be admitted, leaves the law of the case in the same condition as that of the metals. (Plowden, 338, 339, *Ibid.*)

The vexatious and uncertain state of the law, whereby any mine, which might have been discovered at great expense seemed liable, if it contained silver or gold, to be claimed as a royal mine, rendered a legislative change necessary. The Crown, or any person claiming royal mines under it, has only power to purchase such ores (except tin in the counties of Devon and Cornwall), at rates fixed by law. (5 William & Mary, cap. 6.)

11.—Cambrian Formation.—

Below the Silurian strata, in the region of the Cumberland Lakes, in Cornwall, in North Wales, and in other parts of Great Britain, there is a vast thickness of stratified rocks, for the most part slaty and devoid of fossils. In some few places, a few organic remains are detected specifically, and some of them generically different from those of the Silurian period. These rocks have been called Cambrian, by Professor Sedgwick, because they are largely developed in North Wales, where they attain a thickness of several thousand yards. They are chiefly formed of slaty sandstone and conglomerate, in the midst of which is a limestone, containing shells and corals, as at Bala, in Merionethshire. The Llanberis slates, in Carnarvonshire, containing the slates so largely worked at Penrhyn and elsewhere, are situated near the bottom of the Cambrian Formation.

12.—Metamorphic Rocks.—

a *Clay Slate.*
b *Talcose Slate.*
c *Mica Slate.*
d *Hornblende Slate.*
e *Gneiss.*

13.—Volcanic Rocks.—

a *Basalt, &c.*

14.—Plutonic Rocks.—

a *Granite, &c.*

The Metamorphic Rocks consist of a series of crystalline strata divided into beds similar in their arrangement to ordinary aqueous or sedimentary deposits. They contain no organic remains, and are considered to have been originally sedimentary deposits, subsequently changed by the influence of heat into their present condition. The cause of such change is, probably, to be attributed to the Plutonic Rocks upon which they usually rest.

Volcanic Rocks have been produced at or near the surface, by the action of fire or subterraneous heat. They are, for the most part, unstratified: they contain no fossils. The Whin Sill, Toadstone, Basalt, and Whin Stone, already referred to, belong to this class of rocks.

Plutonic Rocks are supposed to be of igneous origin, and to have been formed under great pressure, and cooled very slowly. The consequence is that their texture is very different from that of the Volcanic rocks, being highly crystalline. The component parts of granite are feldspar, quartz, and mica: the proportions are extremely variable, but, in general, the feldspar is the most abundant; sometimes the proportion of quartz is very small, and often the mica is scarcely perceptible. Sometimes, too,

the ingredients of granite are very unequally distributed, and, in particular, the feldspar, which is sometimes disposed in large masses, as is sometimes observed in the island of Arran, as well as in the island of Mull. In the latter, the crystals of feldspar are from one to several inches in diameter.

China Clay, so largely used for the manufacture of China and white pottery ware, is chiefly procured from Cornwall. It consists of decomposed granite.

In some specimens of granite from Arran the mica assumes a crystallised form, the breadth of the crystals not exceeding the thirtieth part of an inch. The quartz of granite is generally of a greyish colour; the feldspar, whitish grey or reddish; and the mica is sometimes black and sometimes white. Besides the three principal ingredients now mentioned, some varieties of granite contain also schorl (as between Penzance and the Landsend, near the Loggan Rock), hornblende, and garnets.

In the granite found at Aberdeen and its vicinity, which, from its appearance, comes under the denomination of grey granite, and which is the description best known here, and which, from the grains of the ingredients of which it is composed being of small size, is called small grained granite, the feldspar and quartz are in the greatest proportion: the quantity of mica is small, and its place is sometimes occupied by small specks of hornblende or schorl.

Although copper and other metallic ores are found and worked in mineral veins traversing the formation lying between the Carboniferous Formation and the Metamorphic Rocks; these, together with the Plutonic Rocks, are the chief repositories of tin and copper in the great mining district of Cornwall.

The ores, as in the case of lead, are found in veins associated with different varieties of spar. The veins in Cornwall have no determinate size, being sometimes very narrow, and at others, exceeding several fathoms in width; extending sometimes to a great length and depth, or terminating after a short course in either direction. As regards their form, they are occasionally, though rarely, contained between parallel and regularly inclined sides or walls, but are continually varying in width, both on the line of their course, and of their inclination, partaking often of the same undulating and even curved form of the rocks which they traverse.

On the kindly appearance of lodes, Mr. Henwood says:—"All the harder rocks in the mining districts are quartzose; and whether they are granite, elvan (porphyry), or slate, this character is unfavourable. A distinctly crystalline structure of the granite, and their slaty texture and high inclination in killas (clay slate), is also discouraging; but a soft nature, both in granite and slate, and in the latter, the moderate thickness of the beds and the slight inclination of the laminæ, are encouraging features. In granite, the lodes, which are chiefly productive of tin ore, are, for the most part, composed of a pale greenish feldspar, of a confusedly crystalline structure, but seldom containing distinct crystals." Tin lodes are, in general, richer or poorer in the elvan than in the adjoining rocks, in proportion to the hardness or softness of the elvan. A

very soft or very hard gossan (brown oxide of iron, similar to the Weardale rider ores of iron already referred to), is equally thought less favourable than if its consistency be moderately firm; and a very dark colour is discouraging. The copper gossans are generally softer, paler, and less quartzose than others. The occurrence of tin in the deeper parts of lodes, which have previously produced copper ore only, is accounted a very unfavourable indication.

It is generally, if not invariably the case, that a peculiarly favourable matrix for copper ore is found at the juncture of killas and granite; and the richest and most numerous veins are generally discovered in killas at no great distance from the granite, and are seldom sought after anywhere else by cautious miners. The pale blue killas generally accompanies a rich vein of copper ore, and it is the easiest to work in sinking shafts and in pursuing discoveries. The lodes vary in width from an inch to thirty feet; but the most general width in tin and copper veins in Cornwall is from one to three feet, and in the thinner veins the ore is less mixed with other substances.

The ores of tin are Tinstone or Oxide of Tin, and Tin Pyrites—the former being the only one extensively worked.

The constituent parts of Oxide of Tin are as follows:—

	CORNWALL.	FINBO.
Oxide of tin	99·00	93·6
Oxide of iron	0·25	1·4
Oxide of manganese	0·00	0·8
Oxide of tantalum	0·00	2·4
Silica	0·75	0·0
	100·00	98·2
Metallic tin	77·56	73·21
	(KLAPROTH).	(BERZELIUS).

Sulphuret of Tin, or Tin Pyrites, is a combination of Sulphuret of Tin and Sulphuret of Copper: it consists of—

Tin	34·0
Copper	36·0
Iron	2·0
Sulphur	25·0
	97·0
It is extremely rare.	(KLAPROTH).

The principal ores of copper are: 1. Sulphuret of Copper: 2. Grey Copper ore: 3. Copper Pyrites; and 4, the Blue and Green Carbonates.

1. Sulphuret of Copper: this consists of—

	SIBERIA.	ROTHENBURG.	CORNWALL.
Copper	78·50	76·5	84·0
Sulphur	18·50	22·0	12·0
Iron	2·25	0·5	4·0
	99·25	99·0	100·0
	(KLAPROTH).		(CHENEVIX).

2. Grey Copper ore, of which the following are analyses :—

LOCALITY.	COPPER.	ARSENIC.	ANTIMONY.	IRON.	SULPHUR.	SILVER.	ZINC.	SILICA.	AUTHORITY.
Freyberg	48·0	14·0	0·0	25·5	10·0	0·5	0·0	0·0	Klaproth.
Gwennap	48·4	11·5	0·0	14·2	21·8	0·0	0·0	5·0	Hemming.
Cornwall	45·32	11·84	0·00	9·26	28·74	0·00	0·00	0·00	Phillips.
St. Marie Aux mines... ...	40·60	10·19	12·46	4·66	26·83	0·60	3·69	0·00	Rose.
Clausthal	34·48	0·00	28·24	2·27	24·73	4·97	5·55	0·00	Rose.
Wolfach	25 33	0·00	26·63	3·72	23·52	17·71	3·10	0·00	Rose.
Corbiers	34·30	1·50	25·00	1·70	25·30	0·70	6·30	0·00	Berthier.
Gersdorf	38·63	7·21	16·52	4·89	26·33	2·37	2·76	0·00	Rose.
Not named...	40·25	0·75	23·00	13·50	18·50	0·31	0·00	0·00	Klaproth.

3. Copper Pyrites: this consists of—

	RAMBERG.	[illegible]	CORNWALL.
Copper	34·40	33·12	30·00
Iron	30·47	30·00	32·20
Sulphur	35·87	36·52	35·16
Silica	0·27	0·39	0·00
	101·01	100·03	97·36
		(ROSE).	(PHILLIPS).

4. Blue Carbonate of Copper consists of—

Oxide of copper	69·08
Carbonic acid	25·46
Water, &c.	5·46
	100·00
Metallic copper	55·2

(Useful metals and their alloys, p. 528). (KARSTEN.)

Green Carbonate of Copper: this consists of—

Oxide of copper	72·20
Carbonic acid	18·50
Water, &c.	9·30
	100·00
Metallic copper	57·7

(*Ibid*). (KLAPROTH.)

CHAPTER II.

BUILDING STONE—SLATE—BRICKS—LIME.

The above formations, besides metals, salt, coal, &c., generally produce stone; clay, indurated or otherwise, from which bricks may be manufactured, these being, in fact, artificial stone; and lime or cement stone, from which lime or cement may be prepared suitable for building purposes.

The admirable report of Sir Henry de la Bèche, Messrs. Barry, Wm. Smith, and C. H. Smith, being the result of an inquiry undertaken under the authority of the Lords Commissioners of Her Majesty's Treasury, with reference to the selection of stone for building the new Houses of Parliament, affords most ample information and invaluable remarks upon the subject.

The report, dated March 16th, 1839, states, that in the greater part of the limestone employed at Oxford, in the magnesian limestone of York Minster, and in the sandstones of which the public buildings of Derby are constructed, we find, among numerous other examples, incontestible and striking evidences of the necessity and importance of making ourselves acquainted with the durability of the material of which we construct buildings which are intended to resist the ravages of time.

The unequal state of preservation of many buildings, often produced by the varied quality of the stone employed in them, although it may have been taken from the same quarry, shows the propriety of a minute examination of the quarries themselves, in order to acquire a proper knowledge of the particular beds from whence the different varieties have been obtained.

It frequently happens that the best stone in quarries is neglected, or only in part worked, from the cost of baring and removing those beds with which it may be associated; and, in consequence, the inferior material is in such cases supplied, especially when a large supply is required in a short space of time, and at an insufficient price, which is often the case with respect to works undertaken by contract.

This points to the necessity of proper inspection.

With respect to the decomposition of stones employed for building purposes, the Commission observe, that it is effected according to the chemical and mechanical conditions to which such stones are exposed.

As regards the sandstones that are usually employed for such purposes, and which are generally composed of either quartz or siliceous grains, cemented by siliceous, argillaceous, calcareous, or other matter, their decomposition is effected according to the nature of the cementing substance, the grains being comparatively indestructible.

With respect to limestones, composed of carbonate of lime, or of the carbonates of lime and magnesia, either nearly pure or mixed with variable proportions of foreign matter, their decomposition depends, other things being equal, upon the mode in which their component parts are aggregated—those which are most crystalline being found to be the most durable, while those which partake least of that character suffer most from exposure to atmospheric influences: these, by their absorption of moisture, are seriously affected by frosts.

The effects of the chemical and mechanical causes of the decomposition of stone in buildings, are found to be greatly modified according as such buildings are situated in town or country. The state of the atmosphere in smoky towns produces a greater amount of decomposition in buildings so situated, than in those placed in the open country, where many of the aëriform products which arise from such towns, and are injurious to buildings, are not to be found.

Judging from the evidence afforded by buildings of various dates, there appear to be many varieties of sandstone and limestone, employed for building purposes, which successfully resist the destructive effects of atmospheric influences. Amongst these, the sandstones of Stenton, Whitby, Tintern, Rivaulx, and Craigleith; the magnesio-calciferous sandstones of Mansfield; the calciferous sandstone of Tisbury; the crystalline magnesian limestones of Bolsover, Huddlestone, and Roche Abbey; the oolites of Byland, Portland, and Ancaster; the shelly oölites and limestones of Barnack and Ham Hill; and the siliciferous limestone of Chilmark, appear to be among the most durable. To these, which may be all considered as desirable building materials, may be added the sandstones of Darley Dale, Humbie, Longannet, and Crowbank; the magnesian limestone of Robin Hood's Well; and the oölite of Ketton, although some of them may not have the evidence of ancient buildings in their favour.

The Commission finally recommended the magnesian limestone, or dolomite of Bolsover Moor and its neighbourhood, as being, in their opinion, the most fit and proper material to be employed in the proposed Houses of Parliament.

The material adopted for the purpose was obtained from the same description of stone, and quarried at Anston, about nine miles north of Bolsover.

From the report, it appears that the average price, per cubic foot, at the quarries, for ordinary ashlar stone, was 10·83 pence; the Magnesian Limestones averaging 11·2 pence; the Sandstones, 9·85 pence; and the Oölites, 10·75 pence. 10·83 pence was the average price at seventy-three quarries.

It is probable, however, that these prices were given under extraordinary stipulations.

The following analyses show the composition of these varieties of building stone:—

1.—SANDSTONE.

	CRAIGLEITH.	HEDDON.	KENTON.	MANSFIELD (RED).
Silica	98·3	95·1	93·1	49·4
Carbonate of lime	1·1	0·8	2·0	26·5
Carbonate of magnesia	0·0	0·0	0·0	16·1
Iron, alumina	0·6	2·3	4·4	3·2
Water and loss	0·0	1·8	0·5	4·8

2.—MAGNESIAN LIMESTONE.

	BOLSOVER.	HUDDLESTONE.	ROCHE ABBEY.
Silica	3·6	2·53	0·8
Carbonate of lime	51·1	54·19	57·5
Carbonate of magnesia	40·2	41·37	39·4
Iron, alumina	1·8	0·30	0·7
Water and loss	3·3	1·61	1·6

3.—OOLITE.

	ANCASTER.	BATH (BOX).	PORTLAND.
Silica	0·00	0·00	1·20
Carbonate of lime	93·59	94·52	95·16
Carbonate of magnesia	2·90	2·50	1·20
Iron, alumina	0·80	1·20	0·50
Water and loss	2·71	1·78	1·94
Bitumen	trace.	trace.	trace.

4.—LIMESTONE.

	BARNACK.	CHILMARK.	HAM HILL.
Silica	0·0	10·4	4·7
Carbonate of lime	93·4	79·0	79·3
Carbonate of magnesia	3·8	3·7	5·2
Iron, alumina	1·3	2·0	8·3
Water and loss	1·5	4·2	2·5
Bitumen	trace.	trace.	trace.

		SPECIFIC GRAVITY.	WEIGHT PER CUBIC FOOT.		COMPARATIVE COHESIVE POWER.
			lbs.	oz.	
SANDSTONE	Craigleith	2·232	145	14	111
	Heddon	2·229	130	11	56
	Kenton	2·247	145	1	70
	Mansfield	2·338	148	10	72
MAGNESIAN LIMESTONE ...	Bolsover	2·316	151	11	117
	Huddlestone	2·147	137	13	61
	Roche Abbey	2·134	139	2	55
OOLITE	Ancaster	2·182	139	4	33
	Bath (Box)	1·839	123	0	21
	Portland	2·145	135	8	30
LIMESTONE	Barnack	2·090	136	12	25
	Chilmark	2·481	153	7	101
	Ham Hill	2·260	141	12	57

Among the lower formations, we find granite, gneiss, and syenite to produce building materials, which, for strength, hardness, and durability, occupy the first rank, but they will not resist very high temperature, although gneiss, when the mica in it is very abundant, has, in some cases, been used as a facing for fire-places and furnaces subjected to a strong heat. Granite and syenite are the most suitable for the purposes of cut or dressed stone, particularly in cases where great solidity is indispensable, owing to the large blocks in which they can be procured from the quarry, and the perfect accuracy with which the surfaces can be wrought. Gneiss seldom splits evenly, and is, therefore, more suitable for rubble or hammered stone: it is also an excellent material for flagging stone; and all three of these stones are in common use for structures requiring great solidity and permanency, as for quay walls, sea walls, lighthouses, &c. (Mahan's Civil Engineering.)

With regard to this description of stone, the Commission above alluded to state as follows:—

We have not considered it necessary to extend our inquiry to granites, porphyries, and other stones of a similar character, on account of the enormous expense of converting them to building purposes in decorated edifices, and from a conviction that an equally durable, and in other respects more eligible, material could be obtained for the object in view, among the limestones or sandstones of the kingdom.

Slate, as has been before stated, is found among the lower rocks. It may consist of the ingredients of granite, or of an extremely fine mixture of mica and quartz, or talc and quartz. Occasionally it derives a shining and silky lustre from the minute particles of mica or talc which it contains. It varies in colour from greenish or bluish gray to a leaden hue.

The best slates are very fissile, splitting with a smooth and even cleavage, in a direction more or less transverse to the planes of stratification, resembling in this respect the cleavages, or, as they are called in the north of England, the "cleats" of the coal.

A piece of slate being split to the desired thickness, it is next squared by a knife or cutting edge of steel, the slates being laid over a similar cutting edge. Polishing, when necessary for other purposes than producing roofing slate, is performed by sand, emery powder, and water; and some varieties of slate admit of being sawn, planed, and turned. Slates for roofing and outside work may be tested by the following process:—Put one into an oven until it is perfectly dry and then weigh it; afterwards immerse it in water for some time; when taken out wipe it dry, and again weigh it. Those slates which are found bulk for bulk to acquire the least additional weight by absorption of water, are the fittest for roofing. Good slates should be thin, dense, and of a smooth surface, and should ring with a clear sound when suspended and struck with a hammer.

The names, sizes, and weights, per thousand, of the different descriptions of slates, are as follows:—

	Dimensions.			Weight per Thousand.			
				First Quality.		Second Quality.	
	In.		In.	Tons.	Cwts.	Tons.	Cwts.
Princesses	24	×	14	3	10	4	0
Duchesses	24	,,	12	3	0	3	10
Small Duchesses	22	,,	12	2	15	3	5
Marchionesses	22	,,	11	2	10	...	
Countesses	20	,,	10	2	0	2	10
Wide Viscountesses	18	,,	10	1	15	2	5
Viscountesses	18	,,	9	1	10	...	
Wide Ladies	16	,,	10	1	10	2	0
Ladies	16½	,,	8½	1	5	1	10
Small Ladies	14	,,	8	1	2	1	5

The best brick earth is composed of a mixture of pure clay and sand, deprived of pebbles of every kind, but particularly of those which contain lime or metallic substances, as these, when in large quantities, and in the form of pebbles, act as fluxes, destroy the shape of the brick, and weaken it by causing cavities or cracks. Good brick earth or clay is frequently found in the natural state, and requires no other preparation for the purposes of the brickmaker. When he is obliged to prepare the earth by mixing the pure clay and sand, direct experiments should, in all cases, be made to ascertain the proper proportions of the two. If the clay is in excess, the temperature required to semi-vitrify it, will cause it to warp, shrink, and crack; and if there is an excess of sand, complete vitrification will ensue, under similar circumstances, unless, however, the sand itself should be of a refractory nature, as in the case of powdered firestone.

The quality of the brick depends as much upon the care bestowed upon its manufacture as upon the quality of the clay. The first stage of the process is to dig and temper the clay, which is most effectually done by digging it out in the autumn,

and exposing it to the weather during the winter. When the clay is strong, it should be exposed to the weather in small heaps, and in the spring it will require riddling before being tempered. The clay is tempered by throwing water upon it, and digging and turning it over, the more frequently the better: this is done in the spring. The quantity of water required will depend upon the quality of the clay; no more should be used than is sufficient to make the clay sufficiently plastic to admit of its being easily moulded by the workmen. If too much water be used, the brick will not only be very slow in drying, but it will in most cases crack, owing to the surface becoming completely dry before the moisture of the interior has had time to escape; the consequence of which will be that the brick, when burnt, will be either entirely unfit for use, or very weak.

Great attention is requisite in drying the brick before it is burnt. It should be placed for this purpose in a dry exposure, and be sheltered from the direct action of the wind and sun, in order that the moisture may be carried off slowly and uniformly from the entire surface. When this precaution is not taken, the brick will generally crack from the unequal shrinking arising from one part drying more rapidly than the rest.

The burning and cooling should be done with equal care. A very moderate fire should be applied for about twenty-four hours to expel any remaining moisture from the raw brick. The fire is then increased until the burning is complete, and then the cooling is slowly effected, otherwise the bricks will not bear the effects of the weather. The ordinary mode of burning bricks is the close fire clamp of London, Manchester, &c.—that is, with as little draft as possible; or by having a smouldering fire, which occupies a month or six weeks, the fuel being spread in layers between the bricks. The principle is to stack the bricks close together, and to check the draft as much as possible, the fuel being intermixed with the bricks. The wind is often very troublesome, and drives the fire to one side, by which that is overburnt, and the other side almost useless from not being burnt enough; and the over and underburnt bricks are sometimes in the proportion of 30 or 40 per cent. of the whole. Sometimes the effect of the wind is checked by placing boards against the clamp, but the expense of these from the effect of the fire is very considerable. In some districts the burning of bricks is conducted in kilns which are open at the top, or in some cases, having raised roofs to keep out the rain: these kilns are usually fitted up with fireplaces near the bottom of the sides, and flues from which the heat of the fuel passes upwards through the interstices between the bricks; and by this plan the loss from wind and bad weather is avoided. In others, again, the kilns are dome-shaped: the bricks to be burnt are placed inside, and the firing conducted, as in the last case, from without. This latter mode of burning is required when the clay is very refractory: the Staffordshire blue bricks are burnt in this description of kiln.

Brick, when of good quality, exhibits a fine, compact, uniform texture when broken across, and gives a clear ringing sound when struck. It is found by experi-

ment that good brick, having a specific gravity of 2·168, requires 1,200 lbs. on the square inch to crush it. The ordinary dimensions of a mould for common bricks is 10 inches in length, 5 inches in breadth, and 3 inches in depth inside, the size of the burnt brick being 9 inches, by $4\frac{1}{2}$ inches by $2\frac{3}{4}$ inches, 400 of which are equal to a cubic yard; 100 to a square yard of 9-inch work, and 50 to a square yard of $4\frac{1}{2}$-inch work. It will, however, in practice be found both more convenient and more economical to have the brick somewhat narrower than $4\frac{1}{2}$ inches, and the thickness proportionally more than $2\frac{3}{4}$ inches: the length of the brick should exceed twice the breadth, in order that sufficient space for mortar may be left between the two when laid side by side without making the space between the outside edges greater than will be covered by the 9-inch brick laid lengthways across them. Fewer bricks will also be required to build up any given height of brickwork.

The above description of the process of making bricks refers to bricks called common bricks, made of clay existing naturally in a plastic state. The indurated clay lying beneath many coal seams, and elsewhere, is by the following process converted into firebricks :—

The fireclay, after being brought to the surface, may at once be ground up; but it is generally found that the bricks produced are of a better quality when the clay, before being ground up, has been "weathered," as it is termed, by an exposure to the action of the atmosphere for several months.

The first process in the conversion is to grind the fireclay by placing it upon a metal saucer, over which two heavy rollers, made of stone, and having metal rims, revolve; or by having the rollers stationary, and the saucer to revolve; or by passing the clay between rollers placed near to each other. The ground clay is during the same process swept off the saucer at one side into elevators, by which it is raised and poured into a revolving cylindrical inclined sieve (called a "tympse"), the fine ground clay passing through the meshes, and the coarse clay, down through the cylinder, back to the rollers, where it again is subjected to the grinding process.

The fine clay is then with a little water introduced into a vertical cylinder, called a pug-mill, where it is mixed and pressed downwards by a series of revolving knives, which somewhat resemble screw propellers, and passes out at the bottom of the pug-mill in a fit condition for the moulder.

The moulding and drying of firebricks is conducted under cover; the drying being effected on flats covering flues, which are either heated by small fires made for the purpose, or by the waste heat of the brick kilns: and this practice might with economy be applied to common brick making.

The burning of firebricks is performed in arched or domed kilns at a high temperature.

The following are analyses of fireclays :—

	NEWCASTLE. BLAYDON.	FIFESHIRE. ST. DAVID'S.	STOURBRIDGE.
Silica	52·452	58·77	67·78
Alumina	23·290	25·01	26·13
Peroxide of iron	4·569	3·95	5·20
Protoxide of iron	4·545	"	"
Carbonate of iron	"	0·39	"
Carbonate of lime	"	0·93	"
Lime	0·595	"	1·47
Carbonate of magnesia... ...	"	1·11	"
Magnesia	1·377	"	"
Potash	2·089	0·70	"
Soda	"	traces.	"
Chloride of sodium	traces.	"	"
Sulphuric acid	traces.	"	"
Water	11·083	8·39	"
	100·000	99·25	100·58

"Gannister" is a bed of an extremely siliceous fireclay, which is very hard, and full of Stigmaria roots: it is found beneath some of the seams of coal of the lower coal measures in Lancashire and elsewhere: this, when crushed, and if necessary mixed with a sufficient quantity of a more plastic fireclay to allow of its being moulded, produces bricks of the highest degree of refractoriness.

Lime is made by burning limestone or carbonate of lime in kilns, the limestone being mixed with coal, until the water and carbonic acid are given off.

Limestone which is pure, or nearly so, supports a white heat in calcining without inconvenience; but limestones which yield hydraulic limes fuse easily from the siliceous matter they contain as their necessary ingredient. The calcination of hydraulic limestones should never be pushed beyond a common red heat, the want of intensity being made up for by its duration.

It appears that silica alone is insufficient to make a lime hydraulic, all hydraulic lime containing a certain quantity of clay, composed of silica and alumina in the proportion found in ordinary clays. There are, however, various opinions on this subject.

A good artificial hydraulic lime may be made by mixing 20 parts of dry clay with 110 parts of slaked lime, and recalcining the mixture; but it will in most cases be necessary to make trials, as the proportion of clay will vary according to the nature of the lime: the finest and softest clays are best.—(Vicat on Cements.)

After having been subjected to the process of calcination, the lime has a strong avidity for water, and when perfectly pure it will absorb about three-and-a-half times its bulk in the process of slaking, and the bulk of the hydrate of lime thus formed will be found to have increased in the same proportion.

The magnesian limestone, the mountain limestone, and the lias limestone are among the principal rocks from which we obtain our supply of lime. That from the first, when of its best quality, is considered generally to be more economical than that from the mountain limestone, as it allows of a greater proportion of sand being mixed with it ; but as regards their comparative value for agricultural purposes, the latter is, with a few trifling local exceptions, far superior. The lime from the blue and brown beds of the lias limestone is naturally hydraulic.

Lime is also made from chalk : this description is suitable for interior work, plastering, ceilings, &c.

Good building lime should allow of an admixture of sand in the proportion of 3 parts of sharp sand to 1 of lime : ground or sifted engine ash is superior to sand, producing a harder cement. When a greater proportion than the above of sand exists, the product is a weak mortar which adheres but slightly to the stone, and is apt to become pulverulent.

It is the received opinion that the union of the lime and sand is merely of a mechanical nature, the lime entering the pores of the sand, and thus connecting the particles much in the same way as the particles of granular stones are connected by a natural cement. The sand itself serves the important purpose of causing the mass to shrink uniformly, whilst the hardening or setting of the mortar is still in progress, and thus prevents any cracking, which must always be the result of any irregularity in the shrinking ; it promotes the rapid desiccation of the mass, and is conducive both to solidity and economy, from its superior strength, hardness, and cheapness to lime.

CHAPTER III.

DIKES—SLIPS—FAULTS—MINERAL VEINS—INTERNAL HEAT.

The whole of the stratified rocks described in the first chapter are seldom found to preserve their continuity over any very large extent; but to have it broken at uncertain intervals by what are commonly called Dikes, Slips, or Faults.

The above terms are often applied indiscriminately; and from this indiscriminate use, misapprehensions and misconstructions have frequently arisen: they may, therefore, both appropriately and conveniently, be each confined to the expression of a distinct phenomenon.

1. The term *Dike* may be properly applied only to a wall-like mass of igneous rock protruded through the original strata.

2. The term *Slip* expresses a fracture of strata, with the levels of the relative beds altered on the opposite sides of the fracture; the beds being thus slipped out of their position.

3. The term *Fault* may be applied to any other disturbance, derangement, or irregularity of the strata, not comprised within the meaning of the terms Dike and Slip.

1.—Dikes are understood to be connected with volcanic rocks beneath, from which they have been ejected in a molten state into fissures probably formed by the convulsions causing the eruptions. The substance of which dikes are composed is basalt or trap of different degrees of fineness in the grain, some of it being coarse and granular, and some of fine texture like some of the cinder of iron furnaces. They are similar in composition to the basalt or trap of the Giant's Causeway, to the whin-sill, and to the green rock of South Staffordshire. They are prominent in the North of England, where they have been much examined. In that locality their direction is usually straight, and their magnetic bearing more or less north-westerly, the course of the principal dikes being as follows:—

1. *Hitchcroft Dike*, near Alnwick	N. 72° W.
2. *Acklington Dike*	N. 80° W.
3. *Blyth Dike*	N. 60° W.
4. *Mausoleum Dike*, Hartley	N. 61° W.
5. *Swallow Dike*, Hartley	N. 65° W.
6. *Coaley Hill Dike*	N. 45° W.
7. *Walbottle Dike*	N. 45° W.
8. *Tynemouth Dike*	N. 63° W.
9. *Willington* or *Tudhoe Dike*	N. 82° W.
10. *Cockfield Dike*	N. 45° W.

1.—The HITCHCROFT DIKE is seen in a quarry a little to the west of the turnpike road from Alnwick to Newcastle, about four miles south of Alnwick. The dike is here in the form of a ridge running across the country, the width of the whin being about 69 feet. The ridge is remarkably intersected by a small rivulet to the depth of 40 or 50 feet. The whin is a strong, hard, coarse basalt, and is used for macadamizing roads. In the centre of the dike the whin is most compact, which may either have arisen from the crater having been in this position, the ejected lava flowing, as it were, over itself, and, gradually cooling, forming the sides; or it may have resulted from the greater pressure laid upon it by the external mass. The outer portions are slightly stratified and columnar. In the clay near to the dike are numerous masses of the rock, in angular blocks of various size, such as might be supposed to have been weathered off during the deposit of the bed of clay.—(Plate 23, fig. 1.)

2.—The ACKLINGTON DIKE. The direction of this dike is from a point half-a-mile south of Radcliffe Colliery, near Warkworth, to within a short distance to the north of Acklington Colliery, and thence through the village of Acklington to the Coquet, which it crosses near Brainshaugh, where it has been partially worked. It is probable that the Radcliffe Colliery is situated between the whin dikes of Hitchcroft and Acklington.

3.—The BLYTH DIKE is found in the workings of Cowpen Colliery, and is about a mile south of the river Blyth, and near the town of that name.

4.—The MAUSOLEUM DIKE was discovered and passed through in the workings of the Low Main seam, at the depth of 53 fathoms in the Old Hartley Colliery, its position being nearly underneath the Mausoleum in the Seaton Delaval grounds. By it, the strata are thrown down to the north-east to the extent of 8½ fathoms. This dike consists of two walls of basalt of the thickness respectively of 9 feet and 4 feet 4 inches, separated from each other by a mass of the debris of other strata of the thickness of 8 feet 10 inches.—(Plate 23, fig. 2.)

5.—The SWALLOW DIKE is at Hartley, between 300 and 400 yards south of the Mausoleum Dike, and is a downcast to the north of 12 fathoms. Its course is nearly parallel with that of the Mausoleum Dike, though they diverge a little to the west. This dike passes through the workings of the Low Main seam (depth 103 fathoms), a quarter of a mile north of the pits at Seaton Delaval Colliery, the thickness of the basalt being here 12 feet, with 55 yards of detritus on its south side. The dike is here an upcast to the north of 10 feet, and 17 yards further north is a small slip, or riser to the north, of 3 feet.

6.—The COALEY HILL DIKE has been noticed at length in a paper read by Mr. Buddle to the Natural History Society of Newcastle-upon-Tyne, in January, 1830. It was discovered in the workings of the Beaumont Seam in Montague Main Colliery, near Newcastle, in 1795, at the depth of 108 fathoms below the surface.

Plate 23, figure 3, is a section of the strata passed through in a stone drift cut through the dike at Benwell Colliery.

	FT.	IN.
No. 1.—The seam changed into shattered glance coal, which is diminished in thickness from its full height, 3 feet 4 inches, into a mere leader by the descent of the blue-grey metal roof: from the roof a tongue of the blue-grey metal is protruded into the coal ...	„	„
No. 2.—The bluish grey metal roof passing downwards	3	0
No. 3.—Grey post mixed with crystallized carbonate of lime	7	0
No. 4.—Black metal much mixed with coal and semi-vitrified	6	0
No. 5.—A singular rock, apparently composed of fragments of shale or metal stone, the interstices being filled up with a fine white powder, which is nearly pure alumina, and calcareous spar. The shale composing the substance of this rock is entirely changed in its nature, differing very materially from the general character of the rock as met with in the district	16	0
No. 6.—Basalt	13	0
No. 7.—Compact indurated black metal stone	20	0
No. 8.—Black metal with scares of coal	15	0
No. 9.—Same as No. 3	2	0
No. 10.—Same as No. 2	0	6
No. 11.—Coal, same as No. 1	„	„
	82	6

The section shows that the whin dike does not pass through the Beaumont Seam at this place, but that it merely depresses the seam a few feet below its natural level, thinning it, as by pressure, into a mere leader, and deteriorating the quality of the coal.

On the workings first approaching this point, the impression was that an ordinary slip had been met with, and the leader was followed until the coal was recovered; and it was only when the direct communication was made through what was expected to be the ordinary roof stone, that the true nature of the dike was discovered. It is a matter of doubt whether the whin extends upwards from the Beaumont seam to the Low Main seam or not, or whether or not its vertical extent is limited to the space between those two seams, which is about 30 fathoms. A cinder dike is described in the plan of the Low Main workings, but whether any whin was observed at this dike is uncertain.

The Coaley Hill dike was passed through at Spital Tongues Colliery, near Newcastle, in the workings of the Low Main seam, 42 yards west of the shaft, and at the depth of 58 fathoms below the surface. It hades here considerably to the south-west, overlying at an angle of 30° or 35°.—(Plate 23, figure 4.)

The section across the dike here is as follows :—

	FT.	IN.
Cinder coal	6	0
Basalt	12	0
Loose blocks of sandstone and shale	18	0
Cinder coal	4	0
	40	0

The strata are not dislocated by this dike.

We have a traditionary account that a cinder dike runs across the Newcastle Town Moor, which spoils the coal in the High Main seam for upwards of 100 yards in breadth through the whole extent of the Moor from the Cowgate to the Bull Park, where the coal is supposed to be not more than 20 fathoms from the surface. The High Main seam is here 60 fathoms above the Low Main seam, and from 85 to 90 fathoms above the Beaumont Seam.

From Coaley Hill we do not discover any traces of this dike at the surface until we come to the Ouseburn. Here is a freestone quarry on the east side of the burn : the stone as well as the clay and earth above it, and also the debris which covers the face of the bank from top to bottom, show that the whole has been subjected to a high degree of heat ; and several scattered fragments of basalt, of various shapes and sizes, occur on the south side of the quarry.

This whin dike passes through Old Byker Colliery, the Jane Pit having been sunk about the middle of it. Here the thickness of the whin and cinder coal was 77 yards. It was also found traversing Walker Colliery, and crossing the Tyne at Walker. As found in the latter colliery, it was described by the late Mr. George Hill.—(Winch, Trans. Geol. Society, Vol. 4, p. 22.)

Plate 24 represents its horizontal section taken at the level of the High Main Seam, 100 fathoms from the surface, where cut through at the point A.

	FT.	IN.
No. 1.—Coke (cindered coal)	18	0
No. 2.—Hardish green whinstone, hard and unbroken	9	0
No. 3.—A fissure filled with nodules of whinstone and post, imbedded in a cement of blue slate	0	9
No. 4.—Loose fragments of whinstone and post, imbedded in blue slate, but commonly less deranged	11	3
No. 5.—Hard greenish whinstone, similar to No. 2	18	0
No. 6.—Coke (cindered coal)	10	6
	67	6

Section at B.

	FT.	IN.
No. 1.—Coke, very hard	3	0
No. 2.—A confused mixture of nodules of sandstone, whinstone, pyrites, and calcareous spar (the sandstone predominating), cemented together by pieces of blue and black slate. Water was found, and there was a plentiful discharge of inflammable gas while the drift was being made	18	0
No. 3.—Compact post, with pieces of black argillaceous slate occurring at intervals	10	6
No. 4.—Hard greenish whinstone	25	6
No. 5.—Coke, like that of No. 1...	3	0
	60	0

The Coaley Hill dike also passes through Hebburn Colliery, where it was cut through in the workings of the High Main seam at the depth of 120 fathoms from the surface. In the immediate vicinity of the dike the coal is charred for about 9 feet on either side, and the thickness of the coal reduced.

The section of the seam 10 yards from the dike is as follows :—

	FT.	IN.
Coal	2	2½
Heworth band (post)	1	10
Coal	0	8½
Band, shale	0	2
Coal	2	7¼
	7	6½

Adjoining the dike the section is as follows :—

	FT.	IN.
Coal, charred	1	10¼
Heworth band	2	1
Coal, charred	0	7
Band, shale	0	1¾
Coal, charred	2	3½
	6	11½

The following is a section of the dike at this point :—

	FT.	IN.
Cinder coal	9	0
Basalt mixed with spar	1	6
Basalt	5	0
Do. mixed with freestone and shale detritus	17	6
Basalt	5	6
Do. mixed with spar	0	9
Cinder coal	9	0
	48	3

This whin dike, which appears at the surface at Simonside, a mile-and-a-half south of Jarrow Church, was quarried there for road material. The quarry has for some time been filled up, but the men who worked it stated that it cropped out in Hedworth Burn, at which point they commenced working. They followed it to some distance, probably 50 yards, in which distance it thickened from 6 to 11 feet. It dipped considerably to the north-west, which, on account of the influx of water, stopped their operations.

8.—A Whin Dike, the course of which is nearly parallel with that of the Coaley Hill dike, passes through the workings of Walbottle Colliery. It is situated about 1,400 yards south of the Coaley Hill dike.

9.—The Tynemouth Dike is exposed in the cliff beneath the Light House, and is close to the North Pier. By the Pier works it has been bared on its south side, and is exposed for a considerable distance.—(Plate 25, figure 1.)

The section of the dike is as follows :—

	FT.	IN.
No. 1.—Hard coarse basalt of a dark grey colour, with abundance of reddish crystals of irregular form, and much shaken and crushed	5	9
No. 2.—A soft decayed "core," containing crystals of feldspar: a portion of this (about 12 inches in depth) has been worn out by the action of the spray and weather	0	7
No. 3.—Hard basalt, resembling No. 1	5	10
	12	2

The sandstone adjoining the dike has a slightly bluish tinge, which may have been occasioned by heat, but it is not much altered; the dike does not occasion any dislocation of the strata. The strata passed through at this point by the dike are a portion of the lower new red sandstone, immediately beneath the magnesian limestone. A few yards north of the dike, the magnesian limestone is seen in the upper part of the cliff, but the dipping, or denudation of the surface towards the south point of the cliff, occasions its absence in the immediate vicinity of the dike.

9.—The Willington or Tudhoe Dike, called also the Hett dike, passes about a mile north of Witton-le-Wear, where it was put through in the workings of the Bitchburn Seam at Marshall Green Colliery, at the depth of 8 or 10 fathoms from the surface. It is again found at Willington Colliery, near Bishop-Auckland, where it intersects the coal at the depth of 40 fathoms.

The section of the dike here is as follows :—

	FT.	IN.
Cinder coal	5	0
White stone	4	6
Basalt	10	6
White stone	4	6
Cinder coal	5	0
	29	6

The level of the strata is not altered by the dike.

This dike crosses the Durham and Bishop-Auckland turnpike at the bridge, a quarter of a mile from the London road. It is quarried at Hett for road material, and also near Cassop. It passes through Shotton Colliery at about half-a-mile north of the pits, the depth where put through being more than 180 fathoms, and the thickness of the basalt 67 feet. At about 180 fathoms from the surface, and at the distance of a mile south-east of the Haswell pits, the drifts in the Hutton Seam, after having passed through 40 yards of cinder coal, reached this dike.

A branch of the Willington dike passes through Shincliffe Colliery, near Durham, where it was met with in the Hutton Seam at the depth of 72 fathoms. In one place, where put through, the thickness of the basalt was 8 feet, and it was exceedingly hard; but at a short distance from this point, the whin does not rise into the coal, but appears in the floor of the seam. Immediately upon the whin the coal is converted into a hard cinder, into which veins of whin have been focred up.

10.—The Cockfield Dike is the most considerable dike intersecting the coal field in the North of England.

At Butterknowle Colliery, near the extreme south-west limit of the coal field, this dike is 7½ feet thick, underlying to the north about 15 inches to the fathom, and casting the strata up, 2 fathoms, to the south. It was cut through in the workings of the Bitchburn seam, at the depth of 43 fathoms below the surface. At the distance of 10 feet from the dike is a slip, an upcast to the south of 6 fathoms (Plate 28). The dike is exposed at the surface on the north-west side of Cockfield Fell, near the Lead Yard, and both there and further south-east, on the Fell, it is extensively quarried as a road material. At the latter place it is 22 yards thick. It is here traversed by a slip, a downcast to the south-east of 12 fathoms, by which it is thrown its full breadth of 22 yards out of its regular course, the dike on the south-east side of the slip being at the surface 22 yards north of its position had its course been unchanged. An underlay of 15 inches in the fathom is insufficient to account for this, as a 12-fathom slip would only throw the dike 15 feet out of its course, instead of 22 yards. Possibly the slip may have had a lateral as well as a vertical motion. One fact, at any rate, seems to be established—viz., that the slip took place subsequently to the formation of the dike. It is cut through in the workings of the Bitchburn seam at Cockfield Fell Colliery, at the depth of 25 fathoms below the surface. In working towards it, when within 50 yards, the coal begins to change: it first loses the calcareous spar which occurs in the joints and faces, and begins to look dull, grows tender and short, and loses its quality for burning. As it comes nearer it assumes the appearance of a half-burnt cinder; and on approaching still nearer to the dike, it diminishes in thickness, becoming a pretty hard cinder, and only 2 feet 6 inches thick, the ordinary thickness of the coal being 7 feet. Eight yards further, it is converted into real cinder, and more immediately in contact with the basalt, it becomes by degrees a black sub-

stance called by the miners dant or swad, resembling soot caked together, the seam of coal being reduced to 9 inches in thickness. There is a large portion of pyrites lodged in the roof of that part of the seam which has been reduced to cinder. On each side of the dike, between it and the regular strata, there is a thin gut or core of clay, about 6 inches thick, which turns the water on the rise side and forces it to the surface, forming numerous springs as it traverses the country.

The coal spoiled by the action of this great dike is, in breadth, as follows:—

	YARDS.
Bad short coal, half reduced to cinder	25
Cinder	16
Dant or swad	10
Basalt	22
Dant or swad	10
Cinder	16
Bad coal, as above	25
	124

On Cockfield Fell, the dike is an upcast to the south of 3 fathoms: it runs nearly in a direct line south-east to Maybecks, in Yorkshire. In several parts of its course the dike protrudes to a considerable height above the surface, as at the ridge called Parker's Howe, in Glazedale; at a place in Lownsdale; and especially at Cliff Rigg and Langbargh, in Cleveland, where it forms a very prominent ridge. At Preston and Langbargh, the width of the dike is 70 feet.—(Plate 25, figs. 2, 3, and 4.)

The whole of the above are examples of vertical, or nearly vertical, dikes of basalt intersecting the strata; but as another description—viz., the horizontal whin dike, or tongue, or false stratum, of basalt is sometimes found more destructive in its effects than the vertical dike, we must not omit to mention it.

The whin sill traversing the mountain limestone district in Cumberland, Durham, &c., and the toadstone of Derbyshire, have been already described, and that they ought to be referred to volcanic origin there is no doubt. In these cases, the thickness of the basalt is tolerably uniform; but there are others in which we find the mass to lie in a less stratiform manner, crossing the other strata obliquely and with variable thickness.

An example of this is found in Ayrshire, where in the neighbourhood of Bartonholme, near the river Garnock, the basalt is found in Stephenson Colliery to be of the thickness of 8 feet; at about 300 yards further to the east, the thickness is 15 feet; and further in the same direction, the basalt is found to threaten cutting off the seams of coal both above and beneath in its progress.—(Plate 26, fig. 1.)

In his description of the South Staffordshire coal field (Memoirs of the Geological Survey), Mr. J. Beete Jukes gives full details of the igneous rocks which seem there, for the most part, to be horizontally protruded, where found in the coal measures:

they appear to spread almost uninterruptedly in the lower coal measures from the base of the Rowley Hills, where a capping of basalt 200 or 300 feet thick rests upon the coal measures, through the centre of the district up to Wolverhampton, Bilston, and Bentley.

The summit of the Rowley range is about 700 feet above the level of the sea, and the thick coal lies underneath it at a depth of between 700 and 800 feet. The thick coal and other mines have been worked far underneath the edges of this cap of basalt, and in one or two instances nearly to the centre of the dome without finding any rising column of basalt coming up from beneath.

In the districts affected by the basalt or "green rock" the coal is reduced to an anthracitic state, in which it is to a large extent used in locomotive engines.

We have seen in the case of the slip traversing the dike on Cockfield Fell, a proof of the more recent occurrence of the slip than of the dike: a similar instance occurs in South Staffordshire, where, at Dudley Port, both the coal measures and horizontally intruded green rock are by two slips thrown up to the north and south, forming what is called the Dudley Port Trough Fault. The depression of each slip is 130 yards, and at the level of the thick coal the distance between the slips is 200 yards in the bottom of the trough.—(Plate 26, fig. 2.)—(Johnson: Transactions of Geological Society of Manchester, Vol. 7, p. 88.)

The following is an analysis of "Rowley Rag" or Basalt, by Mr. Henry, of London.—(*Ibid.*)

Specific gravity 2·907.

Silica	49·860
Alumina	12·750
Lime	8·710
Magnesia	4·395
Protoxide of iron	11·380
Peroxide of iron with magnesia	3·260
Soda	5·250
Potash	0·570
Titanic acid	1·330
Phosphoric acid	0·580
Water	2·560
	100·745

In the district between Wolverhampton and Walsall, "green rock" is frequently met with in sheets in the lower measures, varying in thickness from 15 feet to 80 and 90 feet. In the southern part of this tract it lies below the Bottom coal; but between Wolverhampton and Willenhall it cuts up through that coal; and to the north of that is always found the Bottom coal, between it and the Fireclay coal.—(Jukes.)

The Steinsburg, near Suhl, in Germany, is a mountain formed of nearly horizontal beds of variegated sandstone. A basaltic ridge appears on the summit about 66 feet thick. This ridge appears on the surface for a length of 393 feet in a direction from south-west to north-east. On the slope of the hill is a quarry in the sandstone. A society of Geological amateurs united in order to have a gallery pierced from the quarry to the basaltic mass, and at about 26 feet in vertical depth the basaltic was met with, still cutting and traversing all the sandstone beds as it descends. The basalt is separated from the sandstone by a vertical crust of sandstone nearly one inch thick, afterwards by a bed of clay a little more than one inch thick, in which are fragments of sandstone, and which also contains tables of basalt. The basalt is afterwards found in tables disposed parallel to the side of the mass; and lastly, the basaltic mass, full of irregularly disseminated cells. This basalt contains much olivine, hornblende, and feldspar: it also contains fragments of sandstones, but neither variolites nor lavas have been discovered in it.—(Annales des Mines, 1817.)

This dike is evidently similar to those of Cockfield, Hitchcroft, &c., before described.

A very interesting and detailed account of the trap dikes of Anglesea, by Mr. Henslow, occurs in the first volume of the Cambridge Philosophical Transactions, p. 401, &c.; and those of the Hebrides, &c., will be found ably described by Dr. McCulloch, in his account of the Western Islands; and in the Geological Transactions will be found many other descriptions of similar facts.—(De la Bèche, Translations of Geological Memoirs.)

2.—Slips.

It is possible that dikes and slips are in some degree connected with each other in those districts where both are found, both owing their origin to subterranean convulsion. The description of disturbance properly named a slip is, however, of far more frequent occurrence than that which has just been described: it is found to be distributed almost everywhere, the dike being relatively of rare occurrence. Basaltic dikes have occurred posterior to slips, and slips have taken place since the protrusion of dikes. Dikes have been discovered to have penetrated and intersected the chalk, as at Rathlin.—(Conybeare and Buckland, Geol. Trans. 1st series, vol. 3, p. 210, and plate 10.)

The Great Slip at Radstock, which throws down the coal measures to the west 100 fathoms, had concluded its operations prior to the deposition of the new red sandstone which lies horizontally over it: and, as we have seen above, a slip on Cockfield Fell throws out of its course the Cockfield basaltic dike.

In what manner slips have been produced, we cannot determine; but it is most likely that all these phenomena are the consequence of the depression of the strata now situated on the dip side of the slip, and not of the upheaval of those on its rise side. I must be understood to refer to leading slips; for it is impossible to conceive that great convulsions, such as will be hereafter described, could occur without causing

subordinate breaks in the strata, by some of which they might be locally thrust up or down, or forced into almost any fantastic shape. The probability is that slips are due to the settling down of the strata into hollows formed subterraneously by the discharge of volcanic matter occasioned by gases.

The following description of some of the principal slips which have been proved in different coal fields will serve as a sufficient illustration of the nature of this species of dislocation :—

The Great Tynedale Slip, called also the 90-Fathom dike, the Main dike, and the Stublick dike, traverses the coal measures of the North of England from west to east, and throws down the strata to the north from 90 to 180 fathoms.

It passes along the south side of the Midgeholme, Hartley Burn, and Stublick coal fields, and to its influence not only these but probably a large portion of the coal measures of the Newcastle coal field owe their preservation.

At Stublick, several slips have been proved. By the slips at this point, the coal measures on the north, and the mountain limestone measures on the south, are placed in juxtaposition. On the north side of the slip, the coal measures rise to the north at the rate of 1 in 4, though nearer to it the inclination is much greater, consequently they soon crop out.

This slip passes through the Towneley Colliery, about 300 yards south of the Stargate Pit: it crosses the Tyne midway between Newburn and Lemmington, and then passes through the old Montague Main Colliery about 200 yards north of the Benwell Colliery boundary: its course is here east (Mag.), and its downthrow is probably 100 fathoms. From this point it stretches across the north part of Newcastle Town Moor, passing a short distance north of Gosforth Colliery and through Killingworth Royalty, about three quarters of a mile south of the West Moor pits. Its depression is here greatest, being probably not less than 200 fathoms.

It passes through Backworth Royalty about 1,600 yards south of the B pit: in the vicinity of the slip near to which the workings have been prosecuted, the strata dip towards it at the rate of nearly 1 in 2: such is the declivity of the strata occasioned by this great dislocation, that from the B pit to the face of the south workings near the slip, there is a depression of 80 fathoms. At this place the extent of throw is supposed to be about 160 fathoms.

The direction of the slip, which has been, so far, nearly east, is now changed to the south of east, and continued so until, after passing through Earsdon, Murton, and Whitley Royalties, it is traced into the sea a little to the south of Cullercoats, being exposed in the cliffs between Cullercoats Haven and the Long Sands.

By the section (Plate 27) the strata are here apparently dislocated to the extent of from 80 to 90 fathoms.

The coal measures on the north side of the slip, and immediately adjoining to it, are here covered by the lower new red sandstone and magnesian limestone, and at this

point the dip of the permian and carboniferous formations against the slip vary little, if any. There is no lower red sandstone or magnesian limestone either on the top of the slip or on the coal measures which are on the south side of it ; and it is self-evident that the date of this slip was posterior to that of both the carboniferous and permian formations. The same conclusion is also arrived at as regards the whin dike at Tynemouth already described, relatively at least to the lower new red sandstone. The ninety-fathom slip at Cullercoats underlies about 38° to the north, and its direction is N. 87° W.

About 950 yards south of the village of Killingworth the lower new red sandstone is also found on the dip side of the ninety-fathom slip. Here the dip of the red sandstone to the slip is stated to be 15°, whilst the dip of the coal measures is about 30°.—(Hutton, Transactions of the Natural History Society, Newcastle, Vol. 1, p. 73.)

A branch of the ninety-fathom slip passes from a point north-west of Long Benton through Willington, Percy Main, and Collingwood Main collieries, through North Shields and the Black Middens into the sea below Tynemouth Barracks : it is ascertained to be a downthrow of 40 fathoms to the south in Collingwood Main, but it diminishes in size as it passes through Percy Main and Willington collieries. By this slip, the High Main is thrown completely out, and is wanting to the north of the Chirton pit for about 150 yards, when it is brought in again by a downthrow slip north of 11 fathoms.—(Buddle's Synopsis of Newcastle Coalfield.)

At 120 yards south of the Hilda Pit, South Shields, is a downcast slip to the south of 58 fathoms. The course of this slip is S. 87½° W. It passes through Jarrow Colliery, where it is divided, its principal branch being a downcast south of 6 fathoms.

A downcast slip to the south of 7 fathoms passes beneath the Ouseburn, near the Viaduct ; thence through Heaton and Long Benton Royalties, at which latter place it is divided into two slips, the southern branch being a downcast north of 9½ fathoms, and the northern branch a downcast south of 8 fathoms. Near to the Craster pit, they re-unite, and pass on to Shire Moor, where they form a downcast south of 14 fathoms.

A slip, called the Delight Pit Dike, so named from its having been discovered in the Delight pit, Walker Colliery, runs through Wallsend Colliery from east to west, passing at 150 yards south of the "A" pit, where it is a downcast to the south of 5½ fathoms, and at 88 yards south of the "G" pit, where it is a downcast of 8½ fathoms.—(Buddle on Mining Records.)

A downcast north-west of 15 fathoms passes through Jarrow Colliery at 150 yards south of the shaft. This slip diminishes to the east, passing under the river through the south part of Percy Main Royalty, and again crossing the river under South Shields, where it is a downcast north of 6 feet. To the west it passes through Hebburn, where it is divided—one branch being a downcast south of 13½ fathoms, and the other about a quarter of a mile further south a downcast north of 14 fathoms. It passes under the river into Walker Colliery.

The Heworth Dike, as it is termed, is a downcast slip to the north of 25 fathoms. This is a well-known slip, having been proved in Farnacres Colliery and in Dunston Haughs, by the skirt of Whickham Banks, and in Blaydon Main Colliery, near to Axwell Park. It is here called the 'Shibdon Dyke.' It then runs in a north-western direction, and crosses the ninety-fathom slip at Stephen's Hall, in Towneley Main Colliery, but in crossing it, it is changed into a downcast south of 4 fathoms. It then continues its line of direction across the Tyne between Close House and Wylam Colliery.—(Buddle's Synopsis.)

A downcast south of 13 fathoms passes through Felling Colliery. This is probably a branch of the Heworth slip.

A slip called the 'Briardean Burn Dike' runs in an easterly direction from its commencement in Holywell Colliery, through the south part of Hartley Royalty. It increases to the east, and where it passes through East Holywell Colliery, its throw is probably from 25 to 30 fathoms down to the north. By this slip the High Main seam, after rising to the surface a little north of Earsdon, is again brought in, and is found throughout a large tract of country. About this line, the quality of the High Main coal changes from that of a rich house coal, as at Earsdon, to an excellent steam coal, as at East Holywell.

The Tanfield or Tantoby Slip is a downcast south of 40 fathoms upon Tanfield Moor, but grows less as it advances east and west. It crosses the Derwent a little below Derwent Cote Forge, and thence runs in an easterly direction, through Hamsterley over Tanfield Moor; from thence by Beamish Hall, and through the south part of Blackburn Fell; from thence near Urpeth Colliery engine, and through the collieries of Birtley Fell, Ouston, Leefield, and Fatfield. It is here a downcast south of about 30 fathoms, and known by the name of the 'Birtley Dike.'

In Leefield Colliery, near the village of Birtley, a spring of salt water issues from the fissures of the slip. (Bailey's Survey of Durham.) This slip also passes through Washington Colliery, where it is a downcast south of 20 fathoms.

A downthrow slip to the west of 18 fathoms passes through Haswell Colliery 1,600 yards east of the pits. Its direction is a little to the east of south: this slip, which passes through the Tudhoe or Hett whinstone dike, is found 120 yards west of the Shotton pits, where it is a downcast to the west of 9½ fathoms.

At 200 yards west of the Shotton pits is another slip, a downcast to the east of 7½ fathoms. Near these slips the inclination is rather rapid, being about 1 in 9 rising towards the west.

Plate 28 is a section across the Auckland Seventy-Fathom Slip, and also across the Cockfield dike, at Butterknowle Colliery, near West Auckland. The slip is a downcast to the south, varying in its amount of throw. At Butterknowle, the dislocation is 70 fathoms; and at Garmondsway Colliery, which was sunk near to it, and on the north side of the slip, the throw is apparently 85 fathoms, it being probable that the

first and second seams proved in drifting south from the shaft (sunk through the slip to the Beaumont or Harvey seam) are the Five-quarter and Main Coal seams. If this be the case, it would appear to discourage the idea that the Byers Green or Whitworth seam is identical with the Brockwell or Bitchburn seam, as this conclusion would almost necessitate the conclusion that, at a point between Butterknowle and Garmondsway, the throw caused by this slip is not less than 120 fathoms. It may, however, be urged that the Garmondsway seam is *not* the Harvey, but the Brockwell.

This slip passes through Woodhouse Close Colliery, near to Etherley Grange farm house. An attempt was made to approach it at this colliery, but owing to the rapid dip of the strata (1 in 3) down to the slip, the drifts were stopped. It traverses Auckland Park; also Westerton Colliery, and about 300 yards north of the Cornforth George pit, where its depression of the strata is from 80 to 90 fathoms. Here it alters its course from being about south 80° east, more towards the south, passing through the shaft at Garmondsway Colliery, and beyond this point eastward it either has not been reached by southern explorations, or it has been suddenly broken up or separated into minor slips.

The same effects that on the Tyne are produced upon the strata adjoining, by the ninety-fathom slip, are produced in Durham by this: the dip of the strata to the slip is similarly rapid, for where the north drifts in the Five-quarter seam at Cornforth were discontinued, the declination of the seam was 23°. The lower new red sandstone and the magnesian limestone are thrown in on the dip side of the slip; the north and south line of basset being removed westward from Coxhoe to Westerton; the lower new red sandstone being seen in the Westerton old quarry, near the Auckland Park gates, and the magnesian limestone about half-a-mile further to the east.

The Lancashire and Cheshire coal field is traversed by many large slips:—and whereas the bearing of the principal slips of the North of England is more or less east and west, that of the Lancashire and Cheshire slips is more or less north and south.

In drawing attention to the leading dikes and slips of the North of England, the order generally observed was that of commencing with the most northerly, and, passing southerly, of crossing their direction: and a similar order may as well be observed in describing the leading slips of this district, and we shall, therefore, commence in the east of the coal field and proceed westward, crossing the direction of the slips as before.

The most easterly slip of great magnitude is that described by Mr. Hull (Geology of the Country around Oldham. Mem: Geol. Survey.) This slip has been worked against along a large portion of its course. It commences south of Fairbottom House, crosses the Medlock at Fairbottom Bobs, and passes by Fitton Hill and Sheepwashes. It then ranges by Oldham Parish Church, and at Edge Lane has a throw of 160 fathoms down to the east. It has been traced northward by Royton High Gate and Hathershaw, in the workings of the Royley mine, which is thrown out on the west side of the fault. North of this it continues its course west of Rochdale, by Oaken-

rod Hall, bringing in the Royley mine (here called the Arley) again, after having cropped out near Hathershaw.

The Red Rock Fault has been traced and worked against throughout a considerable extent of the coal field. It is found skirting the north-west extremity of the North Staffordshire coal field, and against a small colliery working the lowest coal series near Macclesfield. Further north, it is found at Poynton, where the lower Permian sandstone is brought down against the coal measures, as observed in the Norbury Brook. In the Poynton Colliery, a drift was put through what appears to be the slip, at the depth of 100 fathoms from the surface, from the level of the Four-feet seam on the east side of the slip. A large downthrow to the west was crossed, on the west side of which the coal measures were found to consist of red and reddish shales and grits, dipping westward at angles varying from 50° to 70°; on continuing the drift other slips were crossed, the dip of the strata becoming less, and a seam of coal was cut at the distance of 36 yards from the first slip. The thickness of this seam is 3 feet, with a soft dark metal roof, and a very white sagre clay thill. The coal was of fair quality but very tender, as might be expected from its proximity to the slips. The dip is 30° westward, the water level course being north-east, which is the same as that of the four-feet coal on the east side of the slip. This seam of coal is unknown in Poynton on the east side of the slip, consequently the throw at the point of exploration of the slip crossed must be at least 100 fathoms. It exercises a remarkable influence over the coal and other strata in its immediate vicinity; the coal near to the slip for several feet being altered in character, gradually, as it approaches it, becoming harder and less bituminous, and where adjoining it the coal is converted into a very hard, compact, black cinder, similar to that commonly found contiguous to a basaltic dike. A vein of ironstone, three inches thick, which lies eighteen inches above the four-feet coal, is also in a state of hard calcination, and converted into a substance resembling red jasper, capable of receiving a fine polish. The grits and shales are also changed from the usual pale brown and dark grey colours to reds and purples of various tints.

The coal in the vicinity of a small slip which spurs from the Red Rock Fault, is similarly converted into a hard cinder: this substance when put in a common fire will not ignite.

This conversion of coal into cinder in the vicinity of a slip is extremely rare: in the case of a "cinder dike," which was found in the North Biddick Colliery in the Newcastle coal field, it was attributed to the vicinity of a whin dike.

Mr. Hull observes that the position of this slip has been approximately determined by a boring into the lower Permian sandstone west of Bredbury Colliery; and it has been proved in some colliery workings on the right bank of the Tame, opposite Arden Hall.

In a pit 60 yards in depth, sunk on the north bank of the river, above the bend,

a seam of coal 3 feet thick was worked, and according to a statement of Mr. Peter Higson, the levels were driven south for a distance of 100 yards in the direction of Arden Hall, under the red Permian sandstone. Mr. Hull concludes that the throw of the slip here seems to be very small, and that we may infer that it is here on the point of dying out.

A slip having the appearance of being a downcast to the west, but as yet unproved at that point, has been met with in the dip workings of the Denton Colliery, near Stockport, between the Burton Nook pit and Hyde Hall; and the fact of the coal adjoining the slip being converted into a cinder similar to that already described as occurring near the red rock fault at Poynton, and of a similar change in the shales and grits, leads very strongly to the conclusion that the Denton slip, if not identical with that passed through at Poynton, is at least an offshoot from it, the great slip not being far distant. The real magnitude of the dislocation is, therefore, as yet unexplored. Apparently, however, the whole of the slips which have been proved northward and in the same direction are downthrows to the east, thus differing entirely from the red rock fault.

As we approach the central portion of the Lancashire coal field, the direction of the slips, which in the eastern portion has a generally northern magnetic bearing, inclines more to the west of north, and in the western portion, the direction of the slips resembles more closely that of the eastern division: and it may be here observed that whilst most of the great slips of the Lancashire coal field in its eastern division are downthrows to the east or north-east, those of the western division are mostly downthrows to the west.

The Great Irwell Valley slip has been well proved through a large extent of country: it traverses the Clifton and Kersley, and adjoining collieries, near Manchester, where it throws the measures down to the north-east 500 fathoms. In working off the coal in the Ram's mine at Clifton Colliery, near to the slip, a feeder of water was brought down, the quantity being upwards of 600 gallons per minute. This occurred in November, 1865, and the supply is as yet unabated. It throws down the new red sandstone.

A slip of considerable horizontal but small vertical throw is found at Tydesley. In this slip a change of throw takes place at Fourgates, a point about half-way along its course, north of the Albert Colliery. The downthrow is to the south-west. Here, however, the line of fracture terminates, and another commences a few yards to the east of the old line, having a downthrow to the north-east.

The slips of the Lancashire and Cheshire coal field are fully described in the Memoirs of the Geological Survey by Mr. Hull in the Geology of the Country about Oldham, Bolton, Wigan, Stockport, Macclesfield, &c. I shall, therefore, merely extract a short list of the greater dislocations for the purpose of showing the enormous agencies which have affected this fine coal field.

The Great Haigh Fault is a slip commencing near Bickershaw Colliery, which passes northward by Hindley, Kirkless Hall, Haigh, and Arley, and by the west side of Adlington Park: it is a downthrow to the west of 300 fathoms at Kirkless Hall Colliery.

The Great Standish Fault has been proved at Amberswood Colliery to be a downthrow slip to the east of 80 fathoms. It passes under St. Catherine's Church at Ince.

The Giant's Hall Fault is a downthrow slip to the west: it ranges by Abram, west of Ince Hall Colliery, where the throw is 300 fathoms; thence it passes west of Gidlow Lane collieries, and under Giant's Hall, to Standish Church.

The Great Shevington Fault is a slip which passes by Hawkley Hall, east of the John pit at Kirkless Hall, where the throw is about 300 fathoms down to the east. It was proved east of Mossy Lee Colliery, where it brings the Wigan 4-feet and Wigan 5-feet coals against the gannister beds with the mountain mine.

The Great Pemberton Fault is a downthrow slip to the east of 235 fathoms at Tan House Colliery: it passes by Pemberton station, Orrell Colliery, where the throw is 125 fathoms, west of Shevington Colliery to Noah's Ark, where it appears to die out.

The five slips last mentioned run nearly parallel to each other in a direction about magnetic north: they are nearly equally distant from each other, being about 1,400 yards apart.

The Great Upholland Fault has been struck at Lathom Park, in the workings of the Arley mine. Its effect is to throw in on the west the middle series of coal measures which on the east side of the slip had cropped out: it is supposed that its greatest throw is at Whiteledge, where it brings in a strip of the lower beds of the new red sandstone, and that at this point it is not less than 350 fathoms. It diminishes northward.

The Lathom Fault runs parallel with the last. At Albert Colliery, it is a downthrow slip to the east of about 250 fathoms: from this point northward it has not been proved until we reach the outcrops of the Park Mine and other coals at Skelmersdale Colliery, where the throw is reduced to $12\frac{1}{2}$ fathoms.

A slip, called the Great Boundary Fault, which is a downthrow to the west, brings in the new red sandstone on the west side of the Lancashire coal field. It passes near Bickerstaffe Chapel, and about two miles east of Ormskirk. It is at present entirely unproved: its general direction is a little east of north.

As already observed, the general bearing of the great slips of the North of England is more or less east and west; whilst that of the Lancashire coal field is more generally north and south: but inasmuch as we find minor slips in the North of England with a north and south course, and in fact running in almost every direction, we find a similar state of things in Lancashire and Cheshire, the only difference between the slips of the two districts being in their magnitude. We have, in Northumberland and Durham, leading slips of from 50 to 180 fathoms, ranging east and west, with spurs or offshoots

of all dimensions up to 15 or 20 fathoms, apparently following no particular law in their course; and we have, in Lancashire and Cheshire, slips of from 300 to 500 fathoms, ranging north and south, with spurs or offshoots of all dimensions up to 50 fathoms, and the direction of these appears to be equally capricious with those of the northern counties.

It will be observed that, between the slips of the North of England and those of Lancashire and Cheshire, there is one point in which they appear entirely to coincide, and that is in their action as regards the Permian Formation, which with the Coal Formation they seem equally to disturb. As an example of a different order, we may take the Somersetshire Coal Field, and some of the slips by which it is traversed.

In the former cases, the action has been subsequent to the deposition of the Permian and Triassic Formations; these and the Coal Measures having been dislocated in an equal degree. In the latter, although the explorations of the Somersetshire Coal Field are not so complete as in the former, sufficient is known to prove the fact that the dislocations of the Coal Measures caused by the great slips were, as a rule, produced prior to the deposition of the Permian and Triassic Formations.

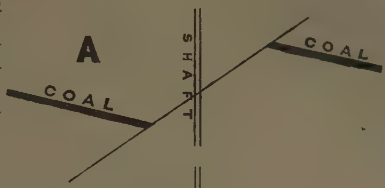
The slip, called at Radstock the Great Fault, the direction of which is about north and south (mag.), and the course of which is proved along a considerable extent, has been put through at Radstock by means of a stone drift, and proved to be a downthrow to the west of 100 fathoms; and this disturbance has occurred without producing any effect upon the Permian (?) trias and lias, which throughout the whole district preserve their unbroken continuity. And the same continuity prevails in most, if not in all cases, where the coal measures beneath have been dislocated by slips. At a small colliery at Twerton, near Bath, it is probable that a drift through a fault passed from the coal measures into the new red sandstone.

It does not appear necessary to multiply cases illustrative of slips, and of the effects produced by them. It may be laid down as an almost universal rule that, if in baring the leader of a slip, it is found to make an acute angle with the floor approaching it, the strata will be thrown down on the far side of the slip; but that, if the leader makes an obtuse angle with the floor approaching it, the strata through the slip will be found to be elevated. To this rule, however, the Somersetshire coal field affords occasionally notable exceptions; the reverse of the above being in the instance of certain overlap faults, as they are called, remarkably the case.

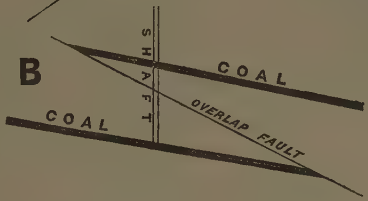
Traversing the Radstock Collieries is a large overlap fault, by which the seams of coal, &c., are forced over themselves to the extent of from 100 to 300 yards, the depression of each seam being in some cases 36 fathoms beneath the same seam above the slip. In its ordinary features the overlap resembles the common slip, the strata being by it altered similarly in level, and the leader presenting no great difference from it.

The hade or inclination of the face of the overlap slip is reversed from that of the ordinary slip, and the underlay is remarkably great. A vertical shaft sunk through the leader of an ordinary slip might miss a seam of coal, as shewn in the diagram A. Whereas, had the slip been an overlap, instead of an ordinary slip, the shaft, instead of missing the coal, would pass through it twice, as shewn in diagram B.

A



B



The Radstock overlap extends for above a mile in Radstock Manor alone. Of smaller magnitude, they are in Somersetshire of frequent occurrence, and in some instances the seams are folded over themselves several times, the seam of 2 feet in thickness being in some instances four times its usual height from this cause, each thickness, however, being clearly discernible, and only separated by a parting from its "doubles."

Plate 29, fig. 1, is an illustration of the folding over and repetition of the Bull Vein coal at Radstock.

In approaching known slips in fiery seams of coal, it is necessary to use great caution, as in the soft coal usually adjacent to them much firedamp is frequently confined, which often escapes with a violence almost explosive. Many serious accidents may probably have arisen from this cause: some have undoubtedly been traced to it, among which may be mentioned the explosion at Jarrow Colliery on August 3rd, 1830, when forty-two lives were lost.—(Mr. Buddle's account of the explosion, Trans. Nat. Hist. Society of Newcastle-on-Tyne, Vol. I.)

When slips extending downwards traverse the formations beneath the coal measures, and especially the limestone beds of the mountain or carboniferous limestone measures, they become frequently metalliferous, and are commonly called mineral veins. Slips have generally between the cheeks of the severed strata a space occupied by the debris of the adjoining rocks; and when they are metalliferous, it is in this debris that the metallic ore is found. In the coal measures, we often find in such situations iron pyrites, and not unfrequently galena and blende: galena was found in considerable quantity in a slip traversing the High Main coal seam at Tyne Main Colliery, near Newcastle-on-Tyne, two men having got out six hundredweights in eight hours. It, however, appeared to be only a small pocket of ore, and died out on each side of the drift which passed through the slip. Occasionally, but very rarely, copper pyrites is found in slips in the coal measures: carbonate of lime is in many instances more abundant. In an economical point of view, however, the quantity of the ores is too limited, and the uncertainty of any being found at all, too great, to make the mineral veins of the coal measures of any practical value.

In Aldstone Moor and the neighbouring districts, the country is chiefly composed of limestone, sandstone, and shale or metal. In the two former the veins produce lead ore, but they are more productive in limestone than in sandstone; but in the beds of shale or metal they are generally unproductive. The most productive veins are those in which the throw is not so great as to throw out of opposition to each other the several faces of the productive rock: thus, should a limestone 3 fathoms in thickness, having 4 fathoms of shale above and 4 fathoms of shale below, have been traversed by a slip of 4 fathoms, limestone on one side of the slip would be opposed to shale on the other side, and the vein would probably be unproductive: whereas had the throw been 2 fathoms, limestone would have been opposed to limestone, and the vein would probably be productive.—(Leithart on Mineral Veins, p. 78.)

The usual contents of mineral veins in the lead-mining districts include clays, spars, metallic ores, and substances, the appearance of which denotes them to be the result of subsequent mechanical and chemical decomposition: these must not be confounded with that associate of the vein, called the rider, which is a part of the rock forming the sides or cheeks of the vein, and which from impregnation with metallic matter has in some cases been converted into an ore: the rider iron ore has been already referred to.

The spars found in the lead veins consist of calcareous spar or crystallized carbonate of lime; fluor spar, Derbyshire spar, or fluate of lime; quartz or silica; heavy spar or sulphate of barytes, and carbonate of barytes or witherite.

1. *Calcareous spar:* constituent parts, lime 56·15; carbonic acid 43·70; specific gravity from 2·5 to 2·8; rhombohedral; generally brittle; not very hard; colour most frequently white and grey, but found also red, blue, green, yellow, brown, and rarely black.

2. *Fluor spar*, or pure fluate of lime: constituent parts, lime 67·75; fluoric acid 32·25; specific gravity 3·0 to 3·3; octahedral; brittle; rather harder than calcareous spar or heavy spar, but not nearly so hard as quartz; colours, white, blue, red, green, grey, and purple. When found compact, it is called by the Derbyshire miners Blue John, and is made into vases and other ornaments receiving a fine polish.

3. *Quartz,* or nearly pure silica: constituent parts, silica 97·75; alumina 0·50; water 1·00; specific gravity 2·5 to 2·7; rhombohedral; brittle; hard; will scratch glass; colour most frequently white; but grey; less frequently black; blue, green, yellow, red, and brown.

Clear transparent colourless quartz forms what are called Clifton, &c., diamonds: when the colour is purple, it constitutes amethyst, and when yellow, cairngorum.

4. *Sulphate of barytes:* constituent parts, barytes 66·0; sulphuric acid 34·0; specific gravity 4·1 to 4·7; prismatic; brittle; not very hard; colour, white, grey, black, blue, green, yellow, red, and brown. It is called also heavy spar: its weight affords facilities

for the adulteration of white lead ; it is, however, clearly the interest of the lead miner not to give any facilities for its employment for any such purpose.

5. *Carbonate of barytes,* or witherite : constituent parts, barytes 79·66 ; carbonic acid 20·00 ; water 0·33 ; specific gravity 4·2 to 4·5 ; prismatic ; brittle ; not very hard ; colours, white, grey, yellow or greenish yellow, and brown.

The ore is sometimes found in ribs or strings in the debris or veinstuff, interposed between the cheeks of the vein, or in masses disseminated through the vein. In Allendale and Aldstone Moor, veins have been found from 6 to 12 feet wide of solid lead ore. About the year 1815, a very rich mining field was opened in Aldstone Moor by John Wilson, Esq., and Co., and known by the name of Hudgill Burn. The mine consisted of two principal veins, denominated the Sun or South Vein, and the North Vein, with other collateral strings or veins between them. The North Vein, in the year 1821, had its east forehead or face 3 feet wide of pure galena, in the tuft or water sill, a bed of post or rock 9 feet thick, and situated here 75 fathoms above the whin sill, and immediately beneath the Great limestone. This vein at Hudgill Burn was in the Great limestone 17 feet wide, consisting of four ribs of galena of the thickness of from 2 to 4 feet each. The Sun Vein at the same time was also about 12 feet wide, blended with galena. This mine has produced upwards of 9,000 bings (8 cwt.) of ore in one year ; it was one of the richest mines ever discovered, and during its most profitable period the number of miners did not exceed eighty.

Veins, however, rarely present this form, but are more usually composed of thin strings of galena disseminated through the vein : even these are by no means regularly met with, and sometimes little ore is found, though many yards of ground may be passed over at much expenditure of time and money.

Most of the same remarks which have been made concerning lead veins apply to those of tin and copper, inasmuch as the repositories of these metals are probably in the same veins, at a lower level.

3.—Faults, under which term may be comprised those irregularities of stratification known as Balks, Swellies, Bad coal, &c., frequently occasion to the miner much inconvenience, and often great expense.

Balks are sudden depressions of the roof into the coal, which usually occur when the roof is sandstone, post, or rock. They are of various size : when small, say under two feet in breadth, and descending not more than a foot or eighteen inches into the seam of coal, they are (in the North of England) frequently called horse-backs, and are in some cases the trunks of trees lying upon the coal, as shown by the stigmaria roots, of the same material, found in their vicinity, penetrating some distance into the coal below the roof : this occurrence may be well observed at Burnopfield Colliery, near Newcastle-on-Tyne, in the workings of the Bustybank seam.

Sometimes, however, the balks descend so far as completely to extinguish the coal, and continue for a considerable distance: when this is the case, they become *Nips.* These are also of frequent occurrence. One in the Pontop district may be named where, for at least 200 yards, there is a continual succession of balks in the Bustybank seam forming an extensive nip. Plate 29, fig. 2, is an example of a balk which occurs in the Bustybank seam at Buropfield Colliery.

Swellies are depressions of seams of coal: the floor and roof dipping into a trough and rising out of it in most cases to such a level as they would have been found to exist, had no disturbance taken place. In such cases the coal in the bottom of the trough or swelly is commonly of unusual thickness.

An excellent example of a swelly is found at Seaton Delaval Colliery, in Northumberland. This swelly is found in the upper coal of Seaton Delaval Low Main seam. It has been described at length by Mr. T. G. Hurst in the Transactions of the North of England Institute of Mining Engineers, Vol. 8.

It extends at least three miles in length: the direction of its synclinical axis is N. 32 E. by the compass: on its west side the seam is nipped out three times in the distance of 50 yards. On leaving the last nip, the seam commences to descend, at first gently, then more rapidly, until at a distance of 150 yards a depression of 30 feet is reached: during the next ten yards the seam is quite level, but immediately thereafter it commences to ascend, and rises regularly for the space of 90 yards, until the summit is gained at an elevation of 24 feet above the point of greatest depression. On each side of the swelly the thickness of the coal is two feet, and from each side it increases in thickness as it approaches the bottom of the swelly, and in the bottom of the trough the thickness is from seven to eight feet.

A similar swelly occurs in the Accommodation seam at Poynton Colliery: in this case the direction of the axis of the trough is N. 19 E. (magnetic), and its breadth 110 yards: the depression at the lowest point is 21 feet 8 inches below the point which would have been the level of the seam had its dip been continuous.

The section of the seam on the edges of the swelly is the same, as follows:—

	FT.	IN.
Roof blue metal.		
Top coal	3	2
Band, fireclay coarse	3	0
Bad coal	0	9
Middle coal	1	5½
Band, black	0	4
Ground coal	3	1
	11	9½

In the bottom of the swelly the section is—

	FT.	IN.
Roof blue metal.		
Top coal	4	1
Band	5	3
Bad coal	0	9
Middle coal	1	10
Band	0	2½
Ground coal	5	4
	17	5½

Showing a thickening to the extent of 5 feet 8 inches in the coal and bands.

A similar instance of a swelly is found in the Bull Vein seam of coal at Radstock, in which a depression occurs of about 20 feet, the thickness of coal being increased from 2 feet 4 inches to 5 feet.

In neither of the last quoted cases is there any nip out of the coal near to the swelly, as in the case of Seaton Delaval.

Bad coal is frequently found to prevail in districts which have been much cut up by slips, but there are many cases in which coal in considerable tracts becomes bad and unworkable from being soft, sooty, or bandy, owing to some unexplained cause. The seams are in some districts shattered to pieces; and in no locality that I am aware of does this description of fault prevail to a greater extent than in the southern portion of the Somersetshire coal field, where a seam of coal may be found in a state of high perfection, and within a few yards, it may be found shattered into fragments; and, again, within a few yards, as suddenly be found in its proper state; and singularly, the fragments when found in their disjointed state do not appear to have suffered the least deterioration in quality. The cost of pursuing the seams under such circumstances is, of course, very great.

We have now examined the strata in their usual or regular form, and also viewed both them and their dislocations, as far as the lowest explored depths: how much further such researches could possibly be prosecuted is perhaps now a fit subject for enquiry.

If we admit that the earth has a proper temperature due to itself, and at the same time take into consideration the feeble conducting power of the substances near the earth's surface, we cannot avoid the conclusion that it is impossible, by the method hitherto pursued, to fix with any certainty upon the mean rate of the increase of temperature as we descend (the usual mode of conducting such experiments being to divide the depth in feet by the difference in temperature between the point of observation underground and the mean temperature of the surface, sometimes deducting from the depth the supposed depth of surface mean temperature say 50 feet); because, if we take a line of equal distance from the centre of the earth, sufficiently distant from the surface to be quite unaffected by solar radiation, we should at this depth (unless

affected by other causes) have the temperatures isothermal: and since in different latitudes, if we were to select points a few feet below the surface we should find the mean temperature lower in cold than in warm latitudes, we must, of course, find that in cold latitudes we should have the rise in temperature as we descend much more rapid than in warm ones. It is, in fact, more than probable that in the tropics the temperature for several hundred feet below the line of surface mean temperature will be considerably under the mean temperature at the surface. The mean temperature at the surface has probably nothing to do with the matter, at least as an agent.

The following is the result of an experiment made by Professor Phillips, at Monkwearmouth Colliery, soon after the sinking of the shaft:—

The depth of the pit at the place of observation was 1,584 feet: the depth below the level of the sea 1,500 feet: the mean annual temperature 47·6°: the observed temperature of the air at the surface on the day of experiment (15th Nov., 1834) 49°: of air at the bottom of the pit, 62°: near the end of the drift, 64°: close to the coal, 68°: temperature of water collected at pit bottom, 67°: of salt water issuing from a borehole made on the same morning, 70·1°: of similar water as it first gushed out, 71·4°: of gas bubbles issuing through the water, 72·6°: temperature of the front of the coal, 68°: of the interior, 71·25°.

A thermometer left in a borehole for a week indicated 71·2°.

If, which for all practical purposes will be sufficiently accurate, we deduct from 71·4°, the temperature of water as it first issued from the borehole, the mean temperature of the surface, 47·6°, we have an increase of 23·8° in 1,584 feet, or 1° Fahrenheit for 69 feet.

My reason for taking the whole depth is partly because most of the experimental results arrived at have been so calculated; but principally from the consideration of Mr. Hopkins' opinion that the mean temperature indicated by thermometers in this latitude placed at depths not exceeding 60 or 70 feet would not exceed the mean temperature given by surface thermometers by more than about 1° Fahr. (Quarterly Journal of Geological Society, 1852.) An increase of 1° in the first 60 or 70 feet removes any necessity for making any deductions from the absolute depth.

According to the experiments of M. Arago upon Artesian wells, the mean results were as follows:—

NO. OF OBSERVATIONS.	DEPTH IN FEET.	INCREASE IN DEG. FAHR.	DEPTH FOR 1° FAHR.
1	216·48	4·14	52·3
2	183·68	3·96	46·4
3	206·64	5·40	38·2
4	328·00	6·66	49·2
5	360·80	9·00	40·1
6	459·70	10·80	42·5

The results from Artesian wells, the water being pure, are probably as much to be depended upon as those from mines.

The results of some other experiments have been recorded by M. Arago.

At Paris, an Artesian well, the "Puits de Grenelle," passes downwards through the chalk to a depth of 1,640½ feet, and though in some parts the temperature increases more slowly than in others, the general result was found to be an increase of 1° Fahr. for every 60 feet.

At Salzwerk, in Westphalia, a similar boring was carried to the depth of 2,114½ feet, and the result was an increase of 1° for every 54 feet.

At Mondorff, in the Grand Duchy of Luxembourg, the result was 1° Fahr. for every 57 feet, the depth in this case being 2,395 feet.

The following are the results of a few observations which I have made upon this subject: they are founded upon the temperatures of small issues of water flowing from the roofs of the various seams of coal:—

PLACES OF OBSERVATION.	DEPTH BELOW SURFACE AND DISTANCE BETWEEN POINTS OF OBSERVATION.		EXCESS ABOVE MEAN TEMP. OF 47° AND INCREASE OF TEMP. BETWEEN POINTS OF OBSERVATION.		DEPTH FOR 1° FAHR. IN ENGLISH FEET.
	DEPTH.	DISTANCE.	EXCESS.	INCREASE.	
	FEET.	FEET.			
Marley Hill Colliery—					
Bustybank seam	432	...	10·5°	...	41·1
Norwood Colliery—					
Beaumont seam	252	...	7·0°	...	36·0
Brockwell seam	468	...	12·5°	...	37·4
Between seams	...	216	...	5·5	39·3
Pontop Colliery—					
Main Coal seam	382	...	10·0°	...	38·2
Bustybank seam	642	...	17·0°	...	37·7
Between seams	...	265	...	7·0°	37·8
Burnopfield Colliery—					
Main Coal seam	288	...	8·0°	...	36·0
Bustybank seam	540	...	15·0°	...	36·0
Between seams	...	252	...	7·0°	36·0
Killingworth Colliery—					
High Main seam	1200	...	23·0°	..	52·1

Several experiments were instituted by Mr. Astley during the progress of sinking the Dukinfield deep pit: they are detailed at length in Mr. Hull's Coalfields of Great Britain, and from them I have made the following extracts, and tabulated them similarly to the foregoing. The observations have not been made at regular distances, and I have found it most convenient to take the lowest observation, or that at the bottom of the pit, and those which are the most nearly 300 feet above it, and above each other:—

NO. OF OBSERVATIONS.	DEPTH BELOW SURFACE AND DISTANCE BETWEEN POINTS OF OBSERVATION.		EXCESS ABOVE MEAN TEMP. OF 51° AND INCREASE OF TEMP. BETWEEN POINTS OF OBSERVATION.		DEPTH FOR 1° FAHR. IN ENGLISH FEET.
	DEPTH.	DISTANCE.	EXCESS.	INCREASE.	
	FEET.	FEET.			
1	639	...	6·70°	...	103·4
2	859·5	...	8·12°	...	105·8
Between points	...	166·5	...	1·42°	117·2
3	1119	...	13.00°	...	86·0
Between points	...	295·5	...	4·88°	53·4
4	1461	...	16·76°	...	87·1
Between points	...	342	...	3·76°	90·9
5	1767	...	20·50°	...	86·2
Between points	..	306	...	3·74°	81·8
6	2055	...	24·50°	...	83·9
Between points	...	288	...	4·00°	72·0

The following observations of the temperature at different depths were made by Mr. Bryham during the sinking of the shaft at Rosebridge Colliery, near Wigan. This shaft is sunk from the surface to the Arley Mine, and is at present the deepest in England :—

NO. OF OBSERVATIONS.	DEPTH BELOW SURFACE AND DISTANCE BETWEEN POINTS OF OBSERVATION.		EXCESS ABOVE MEAN TEMP. OF 51° AND INCREASE OF TEMP. BETWEEN POINTS OF OBSERVATION.		DEPTH FOR 1° FAHR. IN ENGLISH FEET.
	DEPTH.	DISTANCE.	EXCESS.	INCREASE.	
	FEET.	FEET.			
1	483	...	13·5°	...	35·7
2	600	...	15·0°	...	40·0
Between points	...	117	...	1·5°	78·0
3	1674	...	27·0°	...	62·0
Between points	...	1074	...	12·0°	89·5
4	1815	...	29·0°	...	62·6
Between points	...	141	...	2·0°	70·5
5	1989	...	34·0°	...	58·5
Between points	...	174	...	5·0°	34·8
6	2202	...	37·5°	...	58·7
Between points	...	213	...	3·5°	60·8
7	2418	...	42·5°	...	56·9
Between points	...	216	...	5·0°	43·2

The thermometer, in each observation, was allowed to remain 30 minutes in a hole drilled 3 feet into the solid stratum.

The following is an account of depths and observed temperatures at Monkwearmouth Colliery :—

Depth to Hutton seam, "A" pit	1,752 Feet.
Temperature at surface January 16th, 1850	39½° Fahr.
Temperature of intake air currents near bottom of downcast shaft ...	65° „
Temperature of return air near bottom of upcast	82° „
Temperature at surface June 3rd, 1852	57¾° „

Temperature of intake near bottom of downcast	68½° Fahr.
Temperature of return near bottom of upcast	82° „
Depth to bottom of "B" pit	1,080 Feet.
Temperature at surface December 26th, 1849	42° Fahr.
Temperature of intake at bottom of dip inclined plane driven from bottom of "B" pit: length, 1,400 yards, dipping 6 inches in the yard: depth below surface, 1,740 feet	69° „
Temperature in workings	86° „
Temperature at surface January 7th, 1850	39° „
Temperature of intake at bottom of "B" pit...	49° „
Temperature of intake at bottom of inclined plane	62° „
Temperature 350 yards from do. do.	71° „
Temperature 700 yards do. do. do.	72° „
Temperature 1,280 yards do. do. do. ... ... (in face of South workings.)	84° „
Temperature at surface January 16th, 1850	39½° „
Temperature of intake at bottom of "B" pit	47° „

Depth and observed temperatures at Haswell Colliery :—

Depth to Hutton Seam	930 Feet.
Temperature at surface at 4 A.M. June 30th, 1850	55° Fahr.
Temperature of intake near bottom of downcast	57° „
Temperature of return air current near bottom of upcast	64° „
Temperature at surface at 9 A.M.	71° „
Temperature of intake near bottom of downcast	62° „
Temperature of return near bottom of upcast	64° „

From the above observations it appears, that although we have an increase of temperature as we descend, it is not by any means at a uniform rate: in fact, notwithstanding the information we possess on the subject, it must be admitted that, we have not as yet sufficient data to enable us to arrive at any distinct and definite conclusion. I have ventured to hazard the opinion that, although in descending we shall have an increase of temperature, due to the internal heat of the earth, yet, that it does not necessarily follow that it will continue to increase, as we descend, in as great a ratio as it does nearer the surface. This opinion is certainly not corroborated by the results of the experiments at Dukinfield, which are extremely curious. These experiments show that, whereas, between the depth of 693 feet and that of 859·5 feet, the increase of temperature is at the rate of 1° for every 117·2 feet; the increase of temperature between the depths of 859·5 feet and 1,119 feet, is at the rate of 1° for 53·4 feet only; and other similar anomalies occur. Taken, however, as a whole, it would strengthen the above conclusion, for, discarding all observations excepting those taken at the extreme depth of the collieries, we have the following results :—

LOCALITIES.	FOR DEPTH OF	1° INCREASE FOR
Durham Collieries average.........	430 feet.	37·5 feet.
Killingworth.........................	1,200 „	52·1 „
Monkwearmouth....................	1,584 „	69·0 „
Dukinfield............................	2,055 „	83·9 „

The Rosebridge experiments are, however, at variance with this.

The probable temperature of the lower beds of coal in the Lower Rhine is estimated by Baron Humboldt to be 435° Fahr., the depth being upwards of 20,000 feet, and such a temperature would, of course, secure this deposit from the reach of man. If, however, we take the above results, which are sufficiently deep to represent deep mining in the three stages of 1,200, 1,600, and 2,000 feet, each exceeding the one before by 400 feet in depth, and take the increase for these depths at 1° Fahr. for 52·1 feet, 69 feet, and 83·9 feet respectively, we shall observe that for each increase of 400 feet, the number of feet in depth for each degree of increase in temperature is augmented by 16·9 and 14·9 feet respectively: and continuing this ratio, we may infer that, at the depth of 20,000 feet, the temperature would not exceed 200° Fahr.

At what depth the temperature will have risen so high as to render mining no further practicable, it is as yet difficult to say; because, in the first instance, we do not know exactly the ratio of the increase of temperature, and in the next, we cannot say what temperature will arrest our further progress, because, although it is perfectly clear that the same amount of labour cannot be performed in a highly elevated as in a moderate temperature, yet we may call machinery to our aid, and work economically, long after the energy of the human frame must have become exhausted by heat, as the mere directing of a machine may be undertaken, when a very slight degree of bodily exertion would be totally impossible.

In order to show, however, that much may be done in order to cool the natural temperature of a mine by ventilation, I will quote from Mr. Hull's work on the Coal Fields of Great Britain, some experiments made by Mr. C. Wright at Shire Oak Colliery, depth, 1,530 feet.

The intake air had a temperature of 63° Fahr., while the return air was 69°, after a comparatively short circulation. In a goaf, removed seven yards from the air current, the temperature was 72°, and this temperature for 1,530 feet corresponding sufficiently nearly with the temperature of 71·4°, observed by Professor Phillips at the depth of 1,584 feet at Monkwearmouth, to indicate that it was about the natural temperature of the mine.

According to the estimates of the mining engineers of the Continent, the increase of temperature as we descend is equal to 1° Fahr. for every 46·42 English feet: it is highly probable, however, that this rate of increase follows no general law, and that it not only varies in different countries, but even in the different mining districts of the same country.

The following very instructive experiments by M.M. Combes, Glépin, and Jochams, show to how large an extent the theoretical temperature of the air of mines can be reduced by ventilation: the results given will require qualification, as it is quite possible, that in the mines where the experiments have been made, the theoretic temperature may be placed too high: it is much higher than the actual temperature of the

deep coal mines of England, as ascertained by the experiments already referred to. I have, therefore, in each case placed beneath the theoretic temperature of the above experimentalists, what would be the temperature according to the Dukinfield experiments.—("L'Exploitation de la Houille à la profondeur d' au moins mille mètres, by M. A. Devillez.")

Glépin: Experiment of February 4th, 1842 (Bulletin du Musée de l'industrie.)

1. Fosse No. 3 du Grand-Buisson—

Greatest depth to which the air descended	872¾ Feet.
Temperature at surface	35·6° Fahr.
Mean distance run over by the different currents at the point where the temperature was measured	2,624¾ Feet.
Volume of air traversing the galleries	10,304 c. ft. ℘ min.
Number of workmen with lights in the course of the currents	200
Temperature of the return before passing over the ventilating furnace	59·9° Fahr.
Theoretical temperature at the depth of 872¾ feet	65·89° ,,
(Actual temperature at Dukinfield at 879 feet	59·5° Fahr.)

In the experiment, however, it is observed that the temperature of the current was reduced somewhat by being mixed, before arriving at the furnace, with about one-fourth of its bulk of air, which had travelled through higher, and consequently colder workings.

Combes: Experiment of October, 1837 (Traité d'Exploitation.)

2. Mine de l'Esperance near Liége.—

Depth of the point of observation	1,456¾ Feet.
Temperature at surface	51·8° Fahr.
Temperature of the rock at 3·28 feet of depth	66·2° ,,
Temperature of the current of the mine	69·8° ,,
Theoretical temperature at 1,456¾ feet	76·64° ,,
(Actual temperature at Dukinfield at 1,461 feet	67·76° Fahr.)

The excess of the temperature of the current above that of the rock was probably due to the presence of the workmen, and to a ventilation, momentarily a little feeble.

Jochams: Experiment of 3rd August, 1848 (Annales des travaux publics: T. 11.)

3. Siége d'exploitation, No. 5 du Charbonnage du Gouffre.—

Greatest depth in experiment	1,099 Feet.
Volume of air circulating through the works	10,349 c. ft. ℘ min.
Length of run at the point where the temperature was taken	1,132 Feet.
Temperature at surface	64·4° Fahr.
Temperature of air current	59° ,,
Theoretical temperature at the depth of 1,099 feet	70·1° ,,
(Temperature at Dukinfield at $\left(\frac{1074+1119}{2}=\right)$ 1096 ft. = $\left(\frac{62\cdot5^\circ+64^\circ}{2}=\right)$	63·25° Fahr.)

4. Same situation (from the same memoir.)—

Greatest depth in experiment	1,368 Feet.
Volume of air circulating through the works	11,129 c. ft. ℘ min.
Length of course of the current of air, including the faces	3,527 Feet.

Temperature at surface	68° Fahr.
Temperature of air current	64·4° „
Theoretic temperature at 1368 feet	75·02° „
(Temperature at Dukinfield at 1338 feet	67° Fahr.)

5. Same situation (from the same memoir.)

Greatest depth in experiment	1,099 Feet.
Volume of air circulating	16,947 c. ft. ℔ min.
Run of air where temperature was taken	1,132 Feet.
Temperature at surface	68° Fahr.
Temperature of air current	60.8° „
Theoretical temperature at the depth of 1099 feet	70·1° „
(Temperature at Dukinfield at 1096 feet	63·25° Fahr.)

6. Puits No. 2 des Charbonnages réunis de Charleroy (same memoir.) Experiment of October 9th, 1849.

Greatest depth	1361½ Feet.
Total volume of air traversing the works	23,690 c. ft. ℔ min.
Total length of air courses	12,434½ Feet.
Temperature at surface	53·6° Fahr.
Temperature of air current	56·75° „
Theoretic temperature at the depth of 1361½ feet	74·93° „
(Temperature at Dukinfield at 1338 feet	67° Fahr.)

In this experiment it is observed that the air of the mine had probably been cooled in certain points of its course, and had possessed a higher temperature in the deepest part of the workings.

M. Devillez remarks, that in all these experiments the temperature of the air in the works is inferior to the presumed theoretical temperature at the depth at which the mines have arrived ; and that in taking account of the initial temperature which the air possessed before entering the mine, we see that the difference between the presumed and observed temperature is much the greatest where the ventilation is most active, and that the last experiment (6) is above all remarkable, owing to the considerable volume of air which swept through the workings.

The following experiments are extracted from the treatise of M. Devillez, already referred to :—

7. Charbonnage de la Blanchisserie. (End of May, 1856.)—

Depth of pit	1,958¾ Feet.
Volume of air traversing the works	16,920 c. ft. ℔ min.
Temperature at surface	62·15° Fahr.
Temperature of intake at bottom of downcast	55·4° „
Temperature in drill-hole in coal do. : depth, 1,968 feet	56·3° „
Temperature of air current in the face	68° „
Temperature in drill-hole in face	68° „
Temperature of air current at bottom of upcast	62·6° „
Temperature in drill-hole in rock do.	63·5° „
Theoretical temperature at the depth of 1,958¾ feet	84·61° „
(Temperature at Dukinfield at 1,953 feet	72.25° „)

8. Puits No. 4, Trien-Kaisin. (April 16, 1856)—

Depth of pit	1,935¾ Feet
Volume of air traversing the works	12,714 c. ft. ⅌ min.
Temperature at surface	51·62° Fahr.
Temperature of air at bottom of downcast	63·5° „
Temperature in drill-hole in rock do.: depth 5·904 feet	68° „
Temperature of air current in the face	69·54° „
Temperature in drill-hole in coal do.: depth, 5·904 feet	72·5° „
Temperature of air current at bottom of upcast	70·7° „
Temperature in drill-hole in rock do.: depth, 5·904 feet	72·5° „
Theoretical temperature at the depth of 1,935¾ feet	84·2° „
(Temperature at Dukinfield at 1,936½ feet	72·25° Fahr.)

9. Same pit (May 15th, 1856).

Depth of pit	1,935¾ Feet.
Volume of air traversing the works	12,714 c. ft. ⅌ min.
Temperature at surface	56·66° Fahr.
Temperature of air current at bottom of downcast	61·25° „
Temperature in drill-hole in rock do.: depth, 5·904 feet	65·75° „
Temperature of air current in the face	69·54° „
Temperature in drill-hole in coal do.: depth, 5·904 feet	70·7° „
Temperature of air current at bottom of upcast	68° „
Temperature in drill-hole in rock do.: depth, 5·904 feet	70·7° „
Theoretical temperature at the depth of 1,935¾ feet	84·2° „
(Temperature at Dukinfield at 1,936½ feet	72·25° „)

For the temperatures at Dukinfield, *see* "The Coal Fields of Great Britain," by Mr. E. Hull, B.A., p. 167.)

M. Devillez's Treatise contains several other experiments made for the purpose of enquiring as to the extent to which the difficulty opposed to deep mining by internal heat may be overcome: from these I will only extract the following:—

17 Experiment.—At the hanging on or mouthing, at 1,325½ feet in depth, of pit No. 2 of the Charbonnages Belges, two currents of air (previously described) joined together, and having a velocity of 5·249 feet per second, had a temperature of 56·75° Fahr.; the area of gallery being 60·06 square feet.

15 Experiment.—In the Séreuse drift at the same depth, and at 295 feet further along the level, after having passed over ten workmen and eleven lamps, the same current of air, with a velocity of 9·613 feet per second, had a temperature of 54·5° Fahr.; the area of the drift being 32·83 square feet.

The general conclusions arrived at by M. Devillez are—

1. That in the working of coal, the quantity of water which descends into the works through the overlying strata, the evaporation of that water, and the ventilation, lower considerably the normal temperature of the level at which the works are carried on.

2. That by the activity of the ventilation, and by causes previously shown, the natural increase of the temperature of the earth, and the development of the heat occasioned by the presence of the workmen, of horses, and of lights, can be overcome so far as to permit the ordinary work of mining to be carried on without inconvenience, at a depth which at present it is not possible to determine, but which M. Devillez is convinced exceeds (1,000 mètres) 3,281 feet, or say 550 fathoms.

3. And, finally, that if we reached such a depth that the temperature became a grave obstacle to the continuation of the works, we might yet cool the air of the mine, and in consequence the mass of strata which it traverses, by making the current pass through a series of sieves with large meshes upon which water was made to flow, or through narrow airways made artificially wet, such an arrangement only occasioning a slight (?) increase of ventilating power.

In support of these conclusions, the following examples are quoted, dating from an epoch when the ventilation of mines was very imperfect, and when people were generally content with natural ventilation :—

1. A shaft at Kuttenberg, in Bohemia, actually abandoned, had attained the depth of 3,776 feet (Humboldt's Cosmos).

2. In Tyrol, the mountain of Falkenstein, formed of limestone and clayslate, and situated near to Schwatz, a little below Innspruck, in the valley of the Inn, contained mines of argentiferous copper. At one of these, that of Kütz-Pühl, the works had in 1759, according to the report of M. M. Jars and Duhamel, reached the depth of 3,281 feet, and were considered the deepest in Europe, but it was a question as to their abandonment.—(Coup d'Œil sur les Mines par Elie de Beaumont.)

These facts, however, it must be admitted, are capable of a different application, and appear to me to be strongly corroborative of the opinion already expressed.

If the temperature increases uniformly as we descend, at a rate, according to French engineers, of 1° Fahr. to 46·42 feet, the temperature at the bottom of the Kuttenberg shaft would have been (assuming the mean surface temperature to have been 50°) no less than $131\frac{1}{3}$° Fahr. ; and even at the more recent English estimate of 1° Fahr. for every 60 feet, the temperature would have been 113° Fahr.

CHAPTER IV.

BORING FOR COAL—BORING AGAINST OLD WASTES—DAMS—SINKING—TIMBERING—PILING—WEDGING CRIBS—WALLING—SINKER'S TOOLS—METAL TUBBING—STONE TUBBING—PLANK TUBBING—CRIB TUBBING—BRATTICE—PUMPING AND WINDING ENGINES—PUMPS AND CRABS.

ONCE upon a time, the usual way to find, or rather to attempt to find, a vein (and in certain places in England coal seams lie vertically, and are called "Veins"), was to make use of the virgula divinitoria, or divining rod: this implement was also used to discover springs; and be it observed, that where veins (slips) occur, very frequently water exists not very far beneath the surface.

The article upon the subject in Chambers' Dictionary, says that "the virgula is a forked branch in the form of a Y cut off a hazel tree: the person who bears it walking very slowly over the place where he suspects mines or springs may be, the effluvia exhaling from the metals, or vapour from the water impregnating the wood, makes it dip or incline, which is the sign of a discovery." "Some dispute the matter of fact, and deny it to be possible; others, convinced by the great number of experiments alleged in its behalf, look out for the natural causes thereof."

"The corpuscules," say these authors, "rising from the springs or minerals entering the rod, determine it to bow down, in order to render it parallel to the vertical lines which the effluvia describe in their rise, &c."

Howson says that "the first inventor of the virgula divinatoria was hanged in Germany as a cheat and impostor."—(Pryce, Mineralogia Cornubiensis, p. 113.)

Pryce himself seems to have had implicit confidence in its virtues. The virgula is, in the Mendip Hill district, firmly believed in: the implement is there called a "dowzing rod," and the practice "dowzing." The virtue, however, is, I think, more generally supposed to rest in the "dowzer" himself than in his rod: there *may* be some delicate organism in some persons, which *may* be affected in some, ordinarily, incomprehensible manner by these "effluvia," as they are called.

I have seen the rod used, and I have seen it turn and point downwards, apparently without the will of the operator, where mineral veins were certainly probable, but whether there was a vein or not at the identical spot was not investigated: the "dowzer" was blindfolded, and led again and again, with proper precautions, over the spot, and the rod then twisted his hands forward until the single end from being held upwards, pointed vertically downwards, and certainly, so far as I could judge, without any attempt at deception on the part of the operator.

The virgula is fully described, and the mode of using it is illustrated by Agricola, in his Treatise de re Metallicâ, Book 2nd.

He says: "But concerning the forked twig (or virgula) there are many and great contentions among miners; for some say that it is of the greatest use in discovering veins, others deny it." Agricola, however, evidently considers the virgula "uncanny," as he concludes his observations with these words:—

"The miner, therefore, for we give him credit for being a good and sensible man, does not use the charmed virgula, because, skilled in the nature of things, he understands that a forked twig cannot be of any use to him; but, as I have said above, he has natural indications where there are veins, which he observes. Then, if nature or accident has placed them openly in a situation fit for working, there the miner makes his trenches: if she hath not exposed them, he explores the place by frequent diggings until he discovers and lays bare the vein."

The "Compleat Collier," who wrote his book upwards of a century and a half ago, in describing his views on the practicability of finding coals in a certain situation, very much resembles Agricola's "good and sensible man" in his mode of proceeding, for he very sensibly says:—"Sir, my reasons (for hoping to win a colliery on your grounds) are as follows: In the first place, your ground borders on other collieries, which are working collieries, which makes it plain that there is coal so near you, but more especially you may please to observe in your grounds the undoubted tokens or signs of a colliery, which are these following: first, there is an outburst or an appearance above ground of some vein of coal, which some history writers say was the first encouragement to begin work; or secondly, you have an outburst or appearance of such stone as we call coal stone. But if these signs do not assure you thoroughly, we have, in the last place, this undeniable proof and assurance by boring the grounds with proper instruments, whereby we can discover the nature of the earth, minerals, and water that may be met with in our way of sinking; nay, we can thereby discover to a small matter, how deep your coal lies in the earth, and what thickness the coal bed is of."

The search for coal is to be differently commenced, according to the state of our information with regard to the locality in which the search is made; and this information may be classed under three heads:—

Firstly. Where there is no knowledge of the presence of coal in the district to be explored.

Secondly. Where coal is supposed to exist, being found at some little distance from the locality.

Thirdly. Where coal is worked in adjoining properties.

Firstly. The search for coal in a district where we have no information respecting its existence should be commenced by a general survey of the aspect of the country—of the nature of the stratification where exposed by the intersection of ravines, and in the rocky beds of rivers and streams. It will be seen, by reference to the sections of

coal strata before given, that, next to the appearance of coal itself, the occurrence of thin sandstones and soft and dark coloured shales containing fossil plants, the bark of which we find converted into coal, forming what are called coal pipes, is most encouraging. But if, instead of these, strata of chalk, or of the formations lying between it and the coal measures, are met with, we must by such examinations of ravines and river beds, &c., endeavour to find the various outcrops, and by a series of levellings, to estimate the thickness of such formations as we should have to sink through before we could arrive at the position of the coal measures.

After having satisfied ourselves of the rate of inclination, and of the direction of the rise and dip of the strata, our knowledge of the order of superposition of the formations will lead us in the proper direction to seek for the outcrop of the underlying formations; but it is more than probable that should the discovery of coal under the chalk ever be made in England, it will be either accidental, as in the Pas de Calais while boring an Artesian well, or the result of mere experiment. If we should observe limestone containing trilobites, or even abundance of apparently coal shales, but free from coal flora, we may conclude that all labour bestowed upon the search for coal will be expended in vain.

We must also examine the waters of springs, an ochry deposit being a frequent indication of the neighbourhood of the carbonates of iron accompanying coal; but this is not by any means to be relied on, as a similar deposit is often thrown down from certain clays, as well as from peat bogs.

The outcrop of a seam of coal is not unfrequently indicated by a dark shade on the surface of the ground, especially after recent ploughing; and a similar dark shade is often seen under similar circumstances in the clayey banks of rivers or ravines. In either of these cases an examination should be made, the appearance of coal being immediately pursued by an exploring drift driven into the ground or river bank.

If there be a seam of coal, its presence will speedily become manifest: the sooty dark earth will become mixed with grains or small fragments of coal, which will be found more and more frequent as the drift advances. At last the coal will be found of its full height, still very friable, but of its natural quality. The drift should be continued until the roof is found firm and parallel with the floor of the seam.

It will be fortunate for the party engaged in exploring for coal, if the seam found in this manner be of workable thickness and quality; but even should it not be so, it will afford sufficient proof that the country contains coal, and the search for a workable seam may now be conducted with some probability of ultimate success.

Henceforward the means adopted for proving coal in a district such as that in question, apply to that case in which our knowledge is imperfect, and we are, therefore, led to—

Secondly. That case in which the nearest positive existence of coal is at some distance.

In this case we assume it to be known that we have to do with a coal country; an examination of which, with a view to ascertain the direction and dip of the strata, will, therefore, be the first proceeding.

This may be effected by an inspection of any quarries or cliffs, or by a baring off of the alluvial covering when this deposit is of trifling thickness, and must be attended to with care, and the results verified, if possible, by trials in different places, as a little inaccuracy in measuring the dip, or inattention to any local circumstances affecting it, may lead to very erroneous calculations.

To ascertain the angle of dip, the clinometer will be found a useful little instrument, which if used with proper precaution in the selection of the beds, and with a good long "straight edge," so as to average any inequalities they may present, will be found to give results having quite sufficient accuracy for general purposes. It resembles a foot rule (but it may be made of any length) with one joint in the middle: it has a bubble tube inserted in its upper edge, and at the joint is a graduated quadrant of a circle. By placing its lower edge upon a straight edge, laid upon the bed of a rock, in the line of its full dip, and raising the upper edge until the spirit level denotes it to be horizontal, the angle of inclination of the stratum may be observed on the quadrant.

The object in obtaining the direction of the strata and the angle of dip is to furnish data for the determining of situations proper for the exploring of the district by means of boring. It is immaterial whether we commence operations at the rise or dip extremity of the district in course of being explored: we will suppose, however, that a commencement is made at the rise by putting down a borehole to the depth of, say, 30 fathoms. It is evident that no stratum cropping out on the dip side of this borehole will be passed through by it, and the depth of the holes being determined upon, say 30 fathoms, the situation of the next hole will be just so far to the dip of the first that it may at the depth of 30 fathoms from the surface, reach the uppermost stratum passed through by the first borehole.

Supposing the dip of the strata to have been ascertained to be 3 inches in the yard, or 1 in 12, and the surface to be level, the second hole will be required at 720 yards from the first, and the third 1,440, and so on; but the holes had better be placed much nearer together than this, so that if the expected stratum be not found, a dislocation or slip may at once be suspected, and another borehole commenced still nearer No. 1.

It is always best in prosecuting a system of borings to identify some well known stratum; and a top seam of coal, if such should be recognisable, is far the most reliable datum under the system of boring usually practised in England.

Boring is usually contracted for by a master borer, who finds all labour and materials, according to a regular scale of charges, which at present is as follows:—

For the first five fathoms	£0 7 6	per fathom.
„ second „	0 15 0	„
„ third „	1 2 6	„

And so on in arithmetical progression, advancing 7s. 6d. per fathom for every additional 5 fathoms in depth.

The following is the rule for finding the cost of a borehole at the above prices; the depth of the borehole being given, say 60 fathoms :—

Consider the question as a series in arithmetical progression whose first term is $(5 \times 7{\cdot}5\text{s.}) = 37{\cdot}5\text{s.}$, and the last term, 37·5s., multiplied by the number of fathoms divided by 5 :

Here, $\frac{60}{5} = 12$, the number of terms.

$$\left.\begin{array}{r} 12 \times 37{\cdot}5 = 450 \\ 1 \times 37{\cdot}5 = 37{\cdot}5 \end{array}\right\} \text{extremes.}$$

and $\frac{450+37{\cdot}5}{2} \times 12 = £146\ 5\text{s.}$

For boring, however, through very hard rocks the above price is insufficient, and in the case of limestone, or basalt, or whin, either double the above price is charged, or the boring is performed by days-work, according to arrangement.

Boring apparatus consists of three principal parts :—

The *Headgear*, which always remains at the surface :

The *Tools* which pierce the strata : and

The *Rods*, with their appendages which connect the tools with the headgear.

The headgear commonly used in this country consists of

1. A set of shearlegs	Plate 30	Fig. 1 *a*
2. A jack-roll	„	„ *b*
3. Blocks and rope	„	„ *c*
4. A brake	„	Fig. 2
5. Braceheads	„	Fig. 3 *a, b, c, d*
6. A runner	„	Fig. 4
7. A topit	„	Fig. 5
8. Keys	„	Fig. 6

1. The shearlegs or triangles are placed over the borehole for the purpose of supporting the tackle by which the rods are drawn out of, or lowered into the hole, when it is necessary to clean out the hole, or renew the chisel. It is obvious that the more frequently it is necessary to break the joints in drawing and lowering the rods, the more time will be occupied in changing the chisels, or in each cleaning of the hole, and, therefore, the more tedious will the operation become as the depth of the hole increases.

It, therefore, becomes of much importance that the rods should be drawn and lowered as rapidly as possible, and to attain this end as long lengths as practicable should be drawn at each lift.

The length of the lift, or offtake, as it is termed, depending altogether upon the height of the pulley above the top of the borehole, the length of the shearlegs for a hole of any considerable depth should not be less than 40 or 50 feet: and to add still further to their efficiency, they may stand over a small pit or staple, which may be sunk where the clay or gravel is dry to the depth of a few fathoms, from the bottom of which the borehole may be commenced, and here will be stationed the man who has charge of the borehole while working the rods.

There is also another reason for sinking the staple, which is that in proportion to its depth is that of the borehole diminished, a consequence of more importance than appears at first sight; for supposing the depth from the surface to be 100 fathoms, the sinking of the staple 5 fathoms will diminish the cost of boring by the cost of the lowest 5 fathoms, which would amount to £37 10s. The risk of accident, which becomes greater as the depth of the hole increases, is also diminished proportionately by the reduction of the depth; and where time is an object, a saving is effected, the lower boring of deep holes becoming mostly very tedious. The mere convenience of the staple, where practicable, far more than compensates for its small cost.

The shearlegs should be made of three good sound Norway spars, 8 inches in diameter at the bottom, and set upon a frame, as shown in plate 30.

2. The jack-roll may be 12 inches in diameter, properly fitted up with a paul and brake, so as to regulate the speed with which the rods are lowered down into the hole.

3. The blocks may be either single, double, or further multiplied, according to the depth of the borehole, and consequent weight of the rods: and here we observe, that upon this system, with the increased depth of boreholes, instead of the means of drawing and lowering the rods being increased in proportion as regards speed, the reverse is the case.

This at once suggests the application of machinery, which in an easily transportable form, would greatly facilitate the operation of boring, and allow the holes to be continued down, without the extraordinary increase of expense, to considerably greater depths than those usually attained by hand boring.

4. The brake. For boreholes of moderate depths, say under 20 fathoms, the boring is effected, so far as the raising and lowering of the rods is required during the act of piercing the strata by means of a bracehead, which is a piece of rounded oak or ash, 3 feet long and 3 inches in diameter, which passes through an eye in a piece of iron which screws on the top rod: this is called a single bracehead, and by its means two men can bore, without any other aid, to the depth of 10 fathoms. A double bracehead consists of two similar pieces of wood inserted through two eyes at right angles to each other: by it four men may be applied, and a borehole put down to the depth of 20 fathoms. After the hole has reached this depth, the work becomes too heavy for four men, and especially if the depth of the hole is expected to be much

greater, it is advisable to set up a brake, in preference to increasing the number of arms of the bracehead, and of men at the borehole.

A brake is a simple lever made of Memel fir of the length of 10 or 12 feet, the fulcrum being 18 inches or 2 feet from one end, and having an iron crook attached from which the rods are suspended by a piece of rope doubled and passed over the bracehead at the top of the rods. The fulcrum of the brake is an iron axle, working in a carriage bolted to its underside, as shown in the figure. When the hole becomes deep, and the weight of the rods great, the length of the brake may be extended, and a balance weight attached.

The operation of boring with the brake is conducted as follows :—Supposing the rods with a chisel attached to have been lowered into the borehole, we have at the bracehead the master of the shift, and at the brake two men. The men at the brake, by pressing with the necessary weight upon the longer end of the lever, raise the rods: when raised, the master of the shift turns the bracehead partly round, *with* the screw; the men at the brake suddenly release the lever, which instantly allows the rods to fall, and the chisel to cut into the stratum: again the rods are lifted, turned, and dropped, and so on. When the rods drop down into the hole, the master of the shift retains in his hands the bracehead, and by the touch can tell when any change takes place in the stratification.

After this process has, in the opinion of the master of the shift, been continued for a sufficient length of time, the bracehead is unscrewed, and a runner attached to the rope from the jack-roll is passed over the top of the rods and then a topit is screwed on. The two men who were at the brake draw up, by means of the jack-roll, the rods as far as the height of the shearlegs will allow, when the master of the shift, by passing a key upon the top of the rod under the lowest joint drawn above the top of the hole, takes the weight of the rods at this joint, the jack-roll men having lowered the rods for this purpose; with another key the rods are unscrewed at this joint; the rope is lowered down again; the runner put over the rod; another topit screwed on; the rods lifted, and the process continued until the chisel is drawn from the hole and replaced by another, or if necessary, replaced by some other instrument.

Boring tools consist of—

1. Chisels	Plate 30	Fig.	7
2. Wimbles	"	"	8
3. Sludgers	"	"	8
4. Instruments for boring through coal	"	"	9
5. Bèche	"	"	10
6. Rounders	"	"	11

1. The chisel is 18 inches long, and usually $2\frac{1}{4}$ inches in breadth, and at the cutting edge is faced with the best steel: it weighs $4\frac{1}{2}$ lbs. The borer has several of these: they are used to cut through the strata, and require constant attention and

great care, that they may be replaced with fresh ones when any of the substance is worn off their sides so as to diminish their breadth. If this circumstance is not attended to, the size of the hole, of course, decreases, so that when a new chisel of the proper size is put in, it will not pass down to the bottom of the hole, and much unnecessary delay is occasioned in enlarging it.

Whilst using the chisel the borer keeps the bracehead attached to the rods in both hands, one placed on each side of the rods, and at the same time keeps moving slowly round the borehole, so that the chisel may not fall a second time exactly in the same place, the object being to keep the hole perfectly circular and true: in fact, whenever a new chisel is lowered quite down to the bottom, it should be turned round in order to ascertain if the hole is circular and of full size, and if not, the chisel should be raised, and carefully worked until the hole is in a proper state.

An experienced borer can tell to a nicety the nature of any stratum pierced by the chisel, by the peculiarity of the shock, so to speak, occasioned on its striking the rock bored through. It may, however, be remarked that in passing through shale or metal of any description, portions of it are always attached to the chisel when it is drawn to the surface, but that with post or sandstone this is not the case. The rods should be drawn out of the hole, and the chisel examined after boring every six inches, supposing the nature of the stone to be such as to admit this progress to be made; if, however, as it frequently happens, the stone is very hard, so that probably the chisel may be worn off before proceeding half an inch, it still requires to be frequently drawn to the surface and examined for the reason mentioned above.

2. The wimble is 3 feet long altogether, and has the lower 24 inches cylindrical, with a partial covering at the bottom, and an opening a little up one side for the admission of the bruised material, the covering at the bottom being for the purpose of retaining the core with which this instrument fills when working in the hole. The external diameter must be such as to admit of its following the chisel: it weighs about 12 lbs. The wimble is also used in boring through clay, for which it is well adapted: it is turned round in the hole, the cover at the bottom, like that of a shell augur, being a little turned down, occasioning the instrument to penetrate the clay.

3. The sludger is also 3 feet in length, of nearly the same shape as the wimble, the only difference in external appearance being that instead of having an opening near the bottom it is closed to the bottom, near to which there is placed a clack or valve, inside, for the purpose of retaining borings of a soft and "sludgy" nature, or for preventing them from being washed out in a wet hole. Sometimes the wimble is used in boring through coal, and the sludger is often used for bringing up samples of coal bored by the chisel, but left at the bottom of the borehole. The wimble is also sometimes used for this purpose, and in that case it is a common practice to stuff a piece of clay into the bottom of it, to which the fragments of coal adhere. Neither of these plans, however, is quite satisfactory: the samples, when clay is not used, are

apt to be washed away and lost, especially if the hole is deep and wet, and when clay is used, they afford no correct indication of the purity of the coal, and of its freedom from bands of shale.

4. An instrument much better adapted for boring through a seam of coal than any of those yet named was contrived by the late Mr. George Stott, of Ferryhill, near Durham, a master borer of large experience and great accuracy. Its object is two-fold—viz., to break off the coal in such samples as not only to afford specimens of sufficient magnitude to indicate the quality of the seam, but also its hardness and general appearance. It is formed of cylindrical iron, the body being 12 inches long, of similar diameter to the wimble, and tapering at the top to the joint attaching it to the bottom of the bore rods. The bottom of the instrument is serrated, and it has besides two cross-cutters at the bottom within the cylinder, the whole being contrived for the purpose of cutting and not bruising the coal, and answering the object remarkably well. Upon the top of the cutters is also a clack, on which the fragments of coal rest, after being forced into the instrument: near to its top, in the tapering part, is an oblong moveable piece of iron or door, which is screwed into its place by a screw-key before putting the instrument into the hole, which prevents not only any water from washing the coal out, but also any fragments of shale or other upper strata from being mixed with the specimens of coal by being rubbed down into the instrument on its passage out of the borehole. After the instrument has been brought up the door is unscrewed, and the samples taken out.

The difference between the specimens of coal obtained by means of Mr. Stott's instrument and those obtained in the ordinary way is very remarkable: in the latter instance, they are in the form of powder: by the former process, pieces of the size of hazel nuts may be procured. There are, however, advantages obtained by the use of the wimble not afforded by this instrument; and any thin band of shale is more accurately detected when the wimble is used.

5. The bèche is used when the bore rods have broken in the borehole, for the purpose of extracting that portion remaining in the hole: it is a hollow cone, 25 inches long altogether, with a cavity extending upwards 16 inches: it is $1\frac{3}{4}$ inches in diameter internally at the lower extremity, the internal diameter diminishing upwards to $\frac{5}{8}$ inch.

When the rods have broken, the part above the fracture is drawn out of the bore-hole, and the bèche screwed on in place of the broken piece: when this is lowered down upon the broken rod, a smart blow is sufficient to cause the hollow part of the bèche to grip the broken piece with sufficient force to allow the portion below the fracture to be drawn out of the borehole.

6. The rounder resembles a bèche externally, but it is solid and well steeled at the bottom: it is used for breaking off any irregularity which may have been occasioned by careless boring, or by small pieces of iron pyrites or ironstone which may have been too hard to be cut by the chisel with the rest of the strata. The rounder, however, is

an instrument which should seldom be found necessary in boring: in almost all cases proper care will preclude its introduction: all that is required to be done is to round out the hole continually with the chisel, and not to be satisfied with doing this merely at the bottom of the hole, but to have the rods frequently raised a few inches from the bottom, particularly when the hole is making good progress, and ascertain that it is round there; by doing this the hole will always be kept round, and no time will be lost in drawing the rods and putting in the rounder.

The common rods (Plate 30 fig. 12) consist of bars of the best Swedish iron, and may be made either of round, canted, or square iron, but the latter is preferable, as it permits the application of the keys for unscrewing the rods throughout the whole length of each piece. The rods consist of lengths of 3 or 6 feet each, at one end of which is a male and at the other end a female screw, for the purpose of connecting them together. They are made of different degrees of strength, according to the depth of the hole for which they are required, but on the average are 1 inch square, and weigh 22 lbs. to the fathom. The screw should not have fewer than six turns or threads. There are also short pieces, varying from 6 inches to 2 feet in length, which are put on as required at the top, for the purpose of the adjustment of the rods to a convenient height. The common rods being most liable to accident, should be carefully examined every time they are drawn out of the borehole, as an unobserved failure may occasion much inconvenience, and even the loss of the borehole.

A great liability to rupture arises from the splitting of one of the sides of the female screw, and the consequent drawing out of the male screw, thus leaving the rods in the hole. The screw itself may also, by ordinary wear and tear, have its thread worn off, and may, by becoming in consequence liable to slip, occasion the same result.

Besides the above apparatus, there are also frequently required pipes of iron to put into boreholes in strata of soft clay or sand. When this is the case near the surface, the wimble used in boring through the clay should be of sufficient size to admit of the introduction of the pipes as far as the bottom of the first length bored, the depth of which will be dependent upon the judgment of the master borer.

When it is found that the wimble, on being withdrawn from the hole, cannot, from the lateral swelling of the clay, be at once returned to the same depth from which it was drawn, it must be concluded that the sand or clay is of a running or swelling nature. No time should now be lost in enlarging the hole from the surface, or what is better, if the depth be not great, in commencing anew from the surface with a large wimble, say 3 inches in diameter, and putting it down the hole to nearly the same depth with all speed. An iron pipe, say 10 feet long, having an internal diameter of $2\frac{1}{2}$ inches, is then driven into the hole; and when this has been effected, another pipe of similar dimensions is screwed into its upper end, and the drawing is repeated: and so on until a sufficient number of pipes have been put on to reach to the bottom of the hole. If the ordinary wimble be now introduced through these pipes, it will have

free access to the clay or sand, and after a few feet deeper have been bored another pipe may be screwed on and the whole driven further down. In this manner, several fathoms of soft and running material may be bored through. If the thickness, however, of the surface clay or sand be very considerable, the method here mentioned will not be found sufficient, as the friction of the pipes occasioned by the pressure of the clay, &c., will be found so great, that perhaps not more than 12 or 14 fathoms of pipes can be driven in without their being injured. When this is the case, it is necessary to put down the highest part of the hole with a still larger wimble, and to insert pipes of proportionate diameter: then to continue the hole of smaller diameter, putting in another column of pipes of so much smaller size as to admit of their sliding, telescope fashion, down through the first; and thus to proceed until the stonehead is reached.

If, after having passed through upper strata of rock, a stratum of quicksand should be met with at a considerable depth, the process of boring becomes a very expensive one, as the whole of the borehole will require enlargement from the surface, and the insertion of pipes as above described.

The most difficult case of all, however, is when there is a running stratum near the surface, and another at some depth, and beneath the solid strata, both requiring tubing. In this case, if the upper tubing is insufficient in diameter and cannot be drawn out, a new hole from the surface is rendered necessary.

When the borehole is finished, the tubes may be partially recovered by means of a solid box-key, which is tapered slightly towards the bottom (like a railway carriage key), the diagonal dimensions of the bottom of the key being a little less, and of the top a little greater, than the diameter of the tubes, the instrument being in fact the reverse of a bèche. It is also attached to rods having the screws turned in a different direction from the screws of the tubes. When the key is driven down into the uppermost tube in the hole, and turned round by the bracehead, it unscrews the tube, and, as in the case of the bèche, is often sufficient to draw the tube to the surface. Many of the tubes are, however, usually lost.

The application of machinery to boring has been within the last few years making steady progress; one of the early machines, worked by men, was the invention of M. Kind, a German borer of eminence, and has been described by M. Combes. (Traité de l'Exploitation des Mines.)

It consists of a large wheel, called a "Roue à Marches," which is of the diameter of 17 feet, and of the width of 8½ feet (Plate 31), and its operation is as follows:—Six men place themselves inside, and as many outside of the wheel, to turn it round: the lever from which the bore rods are suspended is raised alternately by one of the four rollers, adjusted between the two parallel discs: these rollers are moveable on their axes, in order to diminish friction: the spring, formed of planks, is placed beneath the lever: the elevation of the bore rods can be carried as far as 20 inches.

The bore rods are suspended from the lever by the stirrup, into which they are adjusted by a screw (*e*), which permits the length of the rods to be augmented in proportion to the increase in depth of the borehole: the figure renders any further explanation unnecessary.

This contrivance, however ingenious, must be infinitely surpassed in economical application by a small portable steam engine as above suggested; for the whole of the work, which by the German process appears to require the exertion of a dozen men, could with an engine be easily performed by one.

If it is requisite in the boring to be very minute in the thickness and description of the strata passed through, the apparatus just described appears to be defective: instead of the rods being attached to the lever, they should be suspended from it as from the ordinary brake, so that the master of the shift may have the free handling of the rods by means of the bracehead.

M. Kind by means of the "Roue à Marches" bored at Cessingen near Luxemburg a very deep hole through the following strata (Combe's Traité de l'Exploitation, Vol. I., p. 191):—

	FAS.	FT.	IN.
Lias limestone	34	2	2
Luxemburg grit	45	1	1
Sandy marl	13	5	5
Keuper, with gypsum and saliferous marl	90	4	5
Middle grit	4	5	2
Gypsum and saliferous marl	102	5	6
Fathoms	292	2	9

The hole was commenced of the diameter of 11·81 inches, and at the bottom the diameter was 3·937 inches; Kind made use of iron rods until the depth of 256 fathoms 5 feet 7 inches was reached, when, owing to the frequent rupture of the rods, he substituted wooden rods in the upper part of the hole. He used a valved cylinder attached to a rope for the purpose of lifting the cut strata out of the borehole. This hole was begun on the 6th February, 1837, and stopped on the 22nd March, 1839. The whole expense had not reached 110,000 francs, or £4,441 5s., and two-thirds only of this sum had been employed in the direct work of the boring.

The application of steam machinery to boring has been made by Mr. John Paton, of Govan near Glasgow, in a manner which, in principle, does not appear widely to differ from that of M. Kind's "Roue à Marches."

Steam machinery has also been applied to the purpose of boring by Messrs. Mather and Platt, of Manchester; the principle of boring adopted by them being that of the substitution of a rope of iron, or sheet wire, for rods. (Plate 32.)

The following description of the boring apparatus is extracted from a paper read by Mr. W. Mather to the members of the South Wales Institute of Engineers, July 13th, 1864:—

In the boring tool, and the method of giving the percussive action, as also in the shell pump, especial novelty will be found. Instead of these being attached to rods, as in the old system employed in this country, they are suspended in turn from a flat rope, about ½ inch thick and 4½ inches broad, and the boring tool and pump are let down and drawn up as quickly as the buckets and cages in a coal pit. The rope is wound upon a large drum (*aaa*) by a steam engine with a reversing motion, by which one man can regulate the operation with the greatest nicety and ease. The boring tool, or boring head (*fff*), consists of a wrought iron bar about 4 inches in diameter and 8 feet long, at one end of which a cast iron block is secured. This block has numerous square holes through it, into which the cutters are inserted, in such a way as to be very firm when working, but still readily taken out for repairing and sharpening. Higher up the bar, a little above the block, is another casting, which simply acts as a guide to keep the bar perpendicular. Higher still is another such casting, but on the circumference of this are secured cast iron plates, with ribs of a saw-tooth shape, arranged at such an angle that as they bear against the sides of the hole, when the bar is raised or lowered, they assist to turn it, so that the tool strikes a different portion of the rock at each stroke. Immediately above this is an arrangement by which certain rotation is secured. To effect this, two cast iron collars are cottered fast to the bar about 12 inches apart. On the top edge of one and lower edge of the other collar, deep saw teeth are cut about two inches pitch. The collars are so placed that the perpendicular side of a tooth on the lower one is under the centre of the inclined side of a tooth in the upper one—that is to say, one is placed half a tooth in advance of the other. Between these collars, and sliding freely on the bar, is a deep bush, on the lower and upper edges of which are teeth exactly corresponding with, and fitting into, the teeth in the lower and upper collars. To this bush is attached the wrought iron bow by which the whole bar is suspended by means of a hook and shackle at the end of the flat rope.

The rotary motion of the bar is obtained as follows:—When the bar strikes the rock, the rope is allowed to be a little slack; this causes the bush to which the bow is attached to slide an inch or two down the bar, until it is liberated from the teeth of the top collar, or ratchet, and fits itself into the teeth of the bottom one. But as the teeth of the latter are half a tooth out of direct line with the other, the bush must twist slightly on the bar before the teeth on the underside of it fit completely into the lower collar, or ratchet. This slight turn of the bush, which may be varied by making the ratchets of a coarser or finer pitch, gives a twist to the flat rope, which is increased as the tension is put on, for the bush strikes the teeth of the upper ratchet, where the same action must take place as in the case of the lower one. The result of these motions is, that when the whole weight of the bar is taken by the rope, the latter being flat will naturally assume its straight position, and, in untwisting, takes the bar round with it. This simple but most effective action takes place at every blow of the tool,

and so a constant change in the position of the cutters goes on, and their effect in breaking the rock is necessarily increased.

The shell pump (*ii*) is a cylinder of cast-iron, about 8 feet long, a little less in diameter than the size of the hole: at the bottom is a clack opening upwards, somewhat similar to that in ordinary pumps, but instead of being fastened to the cylinder its seating is in an annular frame, which is drawn up against the end of the cylinder by a rod passing up to a wrought iron guide or bridge at the top, where it is finally secured by a cotter. Above the clack there is a bucket, similar to that of a common lift pump, with an India-rubber clack on the top side. The rod of the bottom clack passes freely through this bucket to be secured at the top, and the rod of the bucket itself is formed like a long link in a chain, the bow or half circle at the top end serving as a means of suspending the whole. A wrought-iron guide is secured to the top of the cylinder to prevent the bucket from being drawn out. The bottom clack has an India-rubber disc, which rises sufficiently to allow water and smaller particles of stone to pass into the cylinder; but in order to enable the broken rock to be brought up as large as possible, the clack itself is capable of rising about 6 inches from its seating on the annular frame, affording ample space for large pieces of rock to have free access into the cylinder when by the upstroke of the bucket a partial vacuum is formed there.

The percussive motion is produced by means of a steam cylinder, which is fitted with a piston of 15 inches diameter, having a rod of cast iron 7 inches square branching off to a fork (*e*), in which is a pulley (*d*) of about 3 feet in diameter, of sufficient breadth for the rope to pass over, and with flanges to keep it in its place.

As the boring head and piston will both fall by their own weight when the steam is shut off and the exhaust valve opened, the steam is admitted only at the bottom of the cylinder: the exhaust port is a few inches higher than the steam port, so that there is always an elastic cushion of steam of that thickness for the piston to fall upon.

The valves are opened and shut by a self-acting motion derived from the action of the piston itself, and, as it is of course necessary that motion should be given to it before such a result can ensue, a small jet of steam is allowed to be constantly blowing into the bottom of the cylinder: this causes the piston to move slowly at first, so as to take up the rope and allow it to receive the weight of the boring rod by degrees, and without a jerk. An arm which is attached to the piston rod then comes in contact with a cam, which opens the steam valve, and the piston moves quickly to the top of the stroke: another cam, worked by the same arm, then shuts off the steam, and the exhaust valve is opened by a corresponding arrangement on the other side of the piston rod. By moving the cams, the length of the stroke can be varied at the will of the operator, according to the material to be bored through. The fall of the boring head and piston can also be regulated by a weighted valve on the exhaust pipe, so as to descend slowly or quickly, as may be required.

The general arrangement of the machine (Plate 32) may be described as follows: The winding drum (*a*) is 10 feet in diameter, and is capable of holding 3,000 feet of rope $4\frac{1}{2}$ inches broad and half-an-inch thick; from the drum, the rope passes under a guide pulley (*b*) through a clam (*c*), and over the pulley (*d*) which is supported on the forked end of the piston rod (*e*), and so to the end which receives the boring head (*f*), which being hooked on and lowered to the bottom, the rope is gripped by the clam (*c*). A small jet of steam is then turned on, causing the piston to rise slowly until the arm moves the cam which opens the steam valve, as before described, and gives the full charge of steam. An accelerated motion is then given to the piston, raising the boring head the required height, when the steam is shut off, and the exhaust opened in the way described, thus effecting one stroke of the boring head as regulated by a back pressure valve on the exhaust pipe.

The exhaust port being 6 inches from the bottom of the cylinder, when the piston descends, it rests on a cushion of steam, which prevents any concussion.

To increase the lift of the boring head or compensate for the elasticity of the rope, which is found to be 1 inch in 100 feet, it is simply necessary to raise the cams on the cam shaft, whilst the percussive motion is in operation. The clam which grips the rope is fixed to a slide and screw, by which means the rope can be given out as required. When this operation is completed, and the strata cut up by a succession of strokes thus effected, the steam is shut off from the percussive cylinder, the rope unclamped, the winding engine put in motion, and the boring head brought up and slung from an overhead suspension bar (*g*) by a hook fitted with a roller (*h*) to traverse the bar.

The shell pump (*i*) is then lowered, the debris pumped into it by lowering and raising the bucket about three times, which the reversing motion of the winding engine readily admits of: it is then brought to the surface and emptied by the following very simple arrangement:—At a point in the suspension bar a hook (*k*) is fixed perpendicularly over a small table (*l*) in the waste tank, which table is raised and lowered by a screw. The pump being suspended from the hook hangs directly over the table, which is then raised by the screw till it receives the weight of the pump. A cotter which keeps the clack in its place is then knocked out, and the table screwed down. The bottom clack and the frame descending with it, the contents of the pump are washed out by the rush of water contained in the pump cylinder. The table is again raised by the screw or lever, and the clack resumes its proper position: the cotter is then driven into the slot, and the pump is again ready to be lowered into the hole as before. It is generally necessary for the pump to descend three times in order to remove all the debris broken up by the boring head at one operation.

By means of this machine a boring of 18 inches diameter was put down at Middlesbrough through strata of new red sandstone to the depth of 1,302 feet, the particulars of which have been already given. In going through the red sandstone,

the maximum rate attained was 13 feet in thirteen hours; and when the depth was upwards of 1,100 feet, a rate of 3¼ feet per thirteen hours was attained.—(Marley, Transactions of the North of England Institute of Mining Engineers, Vol. 13.)

The mode of boring practised in the Western States of North America, such as Virginia, Ohio, Western Pennsylvania, Western New York, and others, is very similar to the above, the apparatus consisting of a drum 5 feet in diameter; hemp rope, wire rope, or hoop iron; a bore spindle of cast or wrought iron (from 200 to 1,000 lbs. weight, according to the size of the hole), at one end of which the hoop iron or rope is fastened by screws, and at the other end of which the bore-bit is inserted in a round hole, and fastened by a flat key; and a pump of sheet iron, which consists of a cylinder from 3 to 4 feet long, ¼ or ½ an inch smaller in diameter than the diameter of the hole, and provided at the bottom with an India-rubber trap valve.—(Overman, Treatise on Metallurgy, p. 39.)

There are circumstances under which the ability to put down boreholes of large diameter must prove of the greatest value: by their means, for instance, pumping arrangements might be made whereby the shafts might be subsequently sunk upon the boreholes through watery strata with great comparative facility; and for all purposes of general exploration, more satisfactory results would probably be attained by large holes conducted as above than by the ordinary mode of boring.

It will sometimes happen that notwithstanding the disposition of the strata with regard to rise and dip may be pretty evident, yet a stratum or bed of coal found in one borehole will not always be found in another, in the situation where by calculation it ought to exist. This will result, in general, from the intersection of the district by slips or dikes; and since it is of the first importance in the establishment of a pit for the purpose of working any stratum, that it should be placed so as to have the greatest possible convenient extent to the rise of the water level from the shaft, every precaution should be taken to define as distinctly as may be the locality in which the winning ought to be made so as to answer this end.

There will probably be in every coal country some top seam or seams which have about them sufficiently characteristic marks to prevent them from being mistaken for others, and the best way to attain the object above specified is to put down a series of boreholes to such seams. By a judicious management of such top borings, no very great expense need be incurred; the cost being well expended if it lead to the prevention of a winning being made in an improper place. Cases however have occurred, and may occur again, in which, notwithstanding all this precaution, errors have arisen, and an instance of an erroneous conclusion, from data as accurate as human skill could possibly have established, will hereafter be related.

We must now proceed to our *third* case, viz., that in which we have coal worked in adjoining properties.

Under the circumstances previously named, it has been supposed that the site of the winning would be altogether governed by the position of the coal seams, it being assumed that, the country being an average one, a railway to the colliery might be constructed to any part of the property indifferently. Now however the case may be somewhat varied, because since we have coal worked in adjoining properties, there will in all probability be a railway already constructed to such collieries as are already in existence, and it may be a matter of moment to have the winning on the tract to be worked placed so as to be convenient for such railway. This, however, is merely mentioned as one of the considerations which may guide us in the selection of the site for the colliery, but which must, so far as practicable, be made subservient to that mentioned under the second case.

If coal is worked on both sides of the district, and by a careful levelling across it made between the pits at work, the strata appear to lie in a regular course, the situation for the winning may be determined at once, and without further expense: still before commencing to sink, it will be prudent to bore in such situation to the seam of coal, if not at a great depth, or to a top seam known at the adjoining collieries, if the depth to the desired seam should be considerable. The reason for taking this precaution is, that notwithstanding that the result of the levelling should be favourable, the section between the two points of known exploration may be crossed by up and downthrow slips of equal magnitude, but possibly of inconvenient size. If there is a top seam not very deep, the expenditure upon a few boreholes may not be regretted. If coal is only worked at one side of the property, a series of borings should be made to the top seam, in order to define by such boreholes a situation eligible for the winning. Much of this, however, must be regulated by circumstances, and no positive rules for proceeding can possibly be laid down.

As the situation for a winning will rarely happen to be confined to a very limited portion of the property, we may regulate it so as in some degree to suit the railway, and also, if possible, so as to have it upon a sloping surface, in order to obtain a ready deposit for the rubbish drawn out during the sinking, and also for the refuse made subsequently in carrying on the works.

The above are general rules, but there are, nevertheless, cases in which the whole of them may require to be set aside. We may be compelled to adopt, knowingly, a most inconvenient situation for a winning, the question being between either having the winning thus inconveniently placed, or having it at an outlay possibly of more than it is worth after having been established.

In certain districts the lower new red sandstone contains a bed of very soft sandstone, which is found in so disintegrated a state that the large feeders of water which are met with in sinking through it, cause it to waste away, and run into the pit bottom with the water. By wearing the leather of the buckets used in pumping, and thus preventing the feeders from being effectively pumped, on the one hand, and in conse-

quence of the sand running into the pit, on the other, the expenses for extra machinery (so as to allow of one portion being continually suspended for refitting) and labour are magnified to an enormous amount. And in such cases, the question as to the site of the winning, becomes that of the best situation for passing through "the sand," and borings shonld be made in different parts of the property to establish this point before commencing to sink.

Much the same directions apply to quicksands near the surface; they are always troublesome, not altogether from the difficulty and expense of sinking through them, but from the insecurity which they cause, by affording a bad foundation to the engine houses and heavy machinery placed upon the colliery. There is no doubt of being able to combat and overcome the difficulties met with in making such winnings, but the safest direction that can be given concerning them is, if possible, to keep out of their way.

An instance has been referred to in which even accurate boring produced erroneous conclusions, and it is given in order to show that boring, although good evidence of the state of things indicated, is not to be implicitly relied on as conclusive on all points. The circumstance was as follows:—

At Cornforth, six miles south-east of Durham, two boreholes were put down in the situations indicated on the section (Plate 33) as No. 1 and No. 2.

SECTION No. 1.

	FT.	IN.	FAS.	FT.	IN.
Soil and clay			1	5	0
Limestone			21	4	6
Red shale and sandstone ...			9	1	9
Coal strata			6	1	3
Coal	1	11			
Band	1	4			
Coal	4	8			
			1	1	11
			40	2	5

SECTION No. 2.

	FT.	IN.	FAS.	FT.	IN.
Soil and clay			0	0	0
Limestone			23	3	6
Red shale and sandstone ...			9	3	4
Coal strata			7	4	6
Coal	1	1			
Band	1	0			
Coal	4	4			
			1	0	5
			41	5	9

This, of course, was sufficient to satisfy any one that the strata between these two points were almost flat, and at the position marked No. 2 a pit was sunk. On the coal strata being reached, however, it was discovered that, instead of being nearly level, they were lying at an angle of 18°, their ascent being to the south at the rate of 1 in 3. At this stage, and still more so on exploring in the direction of borehole No. 1, considerable doubts were expressed as to the accuracy of the boring; and although it was known that at about 14 fathoms beneath the seam sunk to, another seam would be found, it was taken for granted that, even supposing the seam in No. 1 borehole to be the seam lying below that sunk to at No. 2, a more favourable account of it had been given than would be found to be substantiated by fact. However, as it was expected that the lower seam would be of pretty good quality, a stone drift was driven across

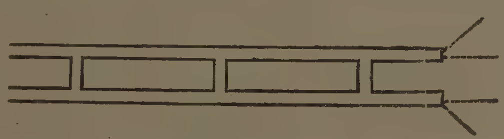
the measures from the bottom of the pit in order to cut it; and subsequently one of the working places intersected the borehole, and it was satisfactorily shewn that the section of the coal, &c., corresponded exactly with the section given in the boring account.

All borings, however, are not as accurate as the above: in faulty districts they are frequently inefficient.

A great liability to error arises from all tender coal boring much harder than it proves to be in reality, for its tenderness or strength when worked depends in a great degree upon the less or greater distance between the cleavages or cleats, which has no relation to the resistance which the coal offers to the chisel; and also from the difficulty of distinguishing any change in the quality of the coal, should one portion of the seam differ from the rest. These errors may to a considerable extent be avoided by the careful use of Mr. Stott's instrument, and for the obtaining of large samples, if necessary, we may employ the machinery and process of Messrs. Mather and Platt.

Besides boring vertically to prove the nature of the stratification, it is frequently necessary to bore horizontally, particularly in coal adjoining to old wastes containing water. For this purpose a lighter description of rod is sufficient, and the breadth of the chisel should not exceed $1\frac{1}{2}$ inch.

The safest plan of driving a pair of exploring drifts against an old waste is to keep them very near together (say 5 yards apart), and not more than 5 feet in width each, and out of each drift to bore one front and one flank hole, as shown in the figure.



The flank holes may be bored every 10 yards. The length of the front holes to be kept in advance of the face of the drifts will depend upon circumstances, for it must be regulated by the vertical depth of the water contained in the waste, and also by the nature of the coal in which the boring is made. Of course also regard must be had to the quantity of water contained in the waste.

If it be intended to draw the water off and the quantity is not of any great consequence, the same care is not so positively requisite as if the contrary were the case; but still it is well in all practice both of this and similar operations to take equally great precaution, because the trouble is very little greater, and the result is always satisfactory and safe. In a moderately hard seam the front holes may be bored out of the face of the drifts 6, 7, 8, 9, or 10, &c., yards in advance, for 5, 10, 15, 20, or 25 fathoms of pressure, the holes being bored forward 2 yards for every 2 yards taken out of the face. This will always insure 4, 5, 6, 7, or 8, &c., yards barrier against the water.

The quantity of water which snch boreholes as those above described will run per minute may be calculated as follows:—

Let, P=the pressure in feet.

d=the diameter of the borehole in feet.

l=the length of the borehole in feet.

v=the velocity at the point of issue in feet per minute.

then

$$v=2837{\cdot}5\sqrt{\frac{Pd}{l}}$$

and

$$525v\times{\cdot}7854d^2=\text{gallons of water per minute.}$$

The actual discharge of a borehole in the Five-quarter seam at Towneley Colliery was 125 gallons per minute, the length of the hole being 25 feet; its diameter $1\frac{1}{2}$ inch; and the pressure of the water 66 feet. Of another borehole in the Towneley seam at the same colliery, the discharge was 140 gallons per minute, the length of the hole being 11 feet, and its diameter $1\frac{1}{2}$ inch; from which it would appear by the above formula that the pressure was 36·4 feet.

According to Eytelwein the formula would be

$$v=60\sqrt{\frac{2500\ Pd}{l+50\ d}}$$

which would give for the discharge of the Towneley borehole $118\frac{1}{4}$ gallons per minute.

After the waste has been proved, the boreholes must be plugged up with long fir plugs, which may be made 4 or even 6 feet long, pointed and slightly tapered so as to admit of easy insertion: they should also be hooped with iron at the head, and some of these, with a mall or heavy hammer, should be in readiness.

It may sometimes be necessary when the pressure is very great to have cross pieces fastened to the plugs, so as to apply the force of two or three men to enter them into the boreholes.

The probable direction of the workings bored into may be pretty accurately conjectured by the direction of the water level; but in order to prevent accidents, it is preferable to drive from some situation not less than 10 or 12 yards back from the face, two pairs of drifts in a water level direction, each pair skirting the waste, and to bore one front and one flank hole out of the drifts nearest to the waste, these being kept the leading drifts.

Of course with these holes it will be necessary to use the same care and precautions as with the holes already described. Should these show no indications of holing at certain distances, other drifts may, with the precautions first named, be driven against the waste until its position is accurately determined. The best plan, however, after having in the first instance proved the waste, is to draw off the water, and lay the old workings dry.

It is imperative on every one having charge of such proceedings as those above described to attend most minutely to the above instructions, as any neglect may be attended by most serious or fatal consequences: so apparently trivial an oversight even as not having the plugs ready, might possibly occasion the drowning up of the colliery.

It is sometimes necessary to put dams in drifts which have been driven through barriers between adjoining properties, worked by means of shafts sunk upon one of them, in order on the expiration of leases, or when required by other circumstances, to protect the colliery which may be continued at work from any influx of water from the property, the connection of which with the colliery has ceased.

Dams are sometimes rendered necessary by other causes: as in driving into new districts, the exploring drifts may meet with water in such quantity that it may be necessary to keep it back: and there have been cases where it was expedient to dam back influxes of water occasioned by pillar working, or otherwise incident to colliery working: and in other mines as well as collieries, dams are not unfrequently necessary from the above or similar causes.

Various plans of dams have been devised, having for their object the resistance of great pressures of water.

The first which I shall describe is, I think, the best, and one which under modifications according to circumstances, may be applied in most cases where any dam is capable of being effectively placed. I allude to the Frame dam (Plate 34, fig. 1).

Before putting in a dam, it is necessary to select with great care a situation where the strata are in a perfectly sound state, and free from slips and faults of every description. As, of course, in preparing such a place for the insertion of a dam, no gunpowder is admissible, on account of its liability to shake the stone or coal, the whole of the work must be performed with the hack or pick, and the sides, as well as the top and bottom, must be dressed perfectly smooth.

The frame dam consists of pieces of fir wood, carefully dressed with a taper, diminishing from that end of each piece nearest to the pressure of water, to that end nearest to the workings which it is designed to protect: and as in proportion to the radius of sweep of the dam will be the ratio of taper it will be necessary to determine upon this, and after projecting it upon a floor at the surface, the pieces of timber of which the dam is to be formed may be dressed there, and properly numbered before being taken into the mine; before which they should also be thoroughly dry.

The length of the pieces of wood must depend upon the pressure which the dam is required to resist, and also upon the area of the dam itself: they may vary from 3 to 8 feet in length, and the radius of the inner circle may be from 18 to 30 feet. Since it has been found that, notwithstanding the most severe wedging, the pressure is sometimes sufficiently great to force the whole dam forward, it is advisable to increase the area of the dam by extending it further into the solid, that its seat may be continued of its tapering form, say, 3 feet further back than the face of the dam, as shown in the plate. While the dam is being put in, it is necessary to have three metal pipes inserted in it: one (*a*) about a foot from the bottom, sufficiently large to allow the feeder of water to pass through, or if the feeder be very large, perhaps two may be preferable; another (*b*) about 18 inches in diameter, two feet from the bottom, for

the purpose of allowing the ingress and egress of the workmen, during the insertion and wedging of the dam; and a third (*c*), which may be an inch in diameter, and placed near the top. This last should, if practicable, be continued of lead or iron tubing to such a level as will outset the water.

After the sides, bottom, and top of the seat of the dam have been accurately dressed, a layer of tarred flannel may be placed next to the coal or stone, and the pieces of wood be built up, inserting the pipes as above until the whole is closed up. The feeder must be conveyed by means of boxes to the water pipe or pipes of the dam, so as that the bottom of the dam may be as accessible to the wedgers as any other part.

The wedging is now commenced on the inside with fir wedges, 12 inches long, 3 inches broad, and 1 inch thick at the head. After these have been driven in at all the joints, sides, and round the pipes, other wedges are driven in, of diminished size, as long as they can be entered, an iron chisel being used to prepare places for their insertion. The wedges must be perfectly dry. After the wedging is finished, the workmen drive the plug into the pipe through which the water has been flowing; they then pass out by the 18 inch pipe before alluded to, drawing after them the plug to close it, which has been placed conveniently for so doing, and the work is completed.

A dam of this description, 6 feet square, and from 6 to 8 feet thick, is able to resist a pressure of from 50 to 100 fathoms of water; but when a less pressure has to be resisted, the dam may be made proportionately of less thickness: although under any such circumstances as render a frame dam necessary, it would be inadvisable to put one in less than 3 feet in thickness.

An excellent and very substantial dam may be constructed of masonry or brickwork. The seat of the dam should be prepared of the same tapering form as in the last case; but in order to resist a similar pressure, the brickwork should be put in at least twice the thickness of the frame dam. The bricks should be laid with cement, or very strong hydraulic lime, and so that the whole should be solidly tied together from front to back of the dam, forming one solid mass of brickwork.

Dams, for slight purposes, may be constructed of balks, accurately dressed, set edgeways upon each other, and opposed laterally to the pressure (Plate 34, fig. 2); or they may be formed of two rows of 3 inch planks, set upon one another, the space between them (say 18 inches) being filled with clay beaten tight in, the planks being kept in their places between two rows of props (Plate 34, fig. 3).

For all permanent work, however, the frame or brickwork dams above described will be found far superior to those last named: and a solid stowing for several yards behind the dam will be found to give greater additional security in all cases.

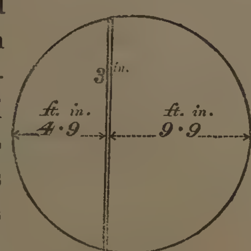
Many instances might be adduced in proof of the necessity of careful boring against old wastes; and upon the general use of boring it may be stated that its great value consists in its enabling us to determine the position of the strata, rather than

the value of individual seams of coal. Mr. William Brown, a celebrated colliery viewer of former days, used to say that a colliery well bored was half won; and so far as the establishment of the best position for effecting the winning is concerned, no doubt he was right.

The site of the winning having been determined upon, we shall now proceed to describe the process of sinking a pit through strata, which we may assume that we have proved by boring to be as follows (Plate 35). A shallow pit is adopted merely for convenience of illustration. In practice, such an establishment as that about to be described, would be applicable to a pit of any depth, no matter how great:—

	FAS.	FT.	IN.
1. Soil, gravel, and clay	3	0	0
2. Magnesian limestone	3	0	0
3. Do. with water	20	0	0
4. Lower new red sandstone or sand with water	4	0	0
5. Blue and red shales	6	0	0
6. Coal	0	3	0
7. Grey shale	3	3	0
8. Rock	10	0	0
9. Blue shale	10	0	0
10. Black shale	2	0	0
11. Rock	15	0	0
12. Coal	1	0	0
	78	0	0

We will also suppose that the diameter of the pit when finished is to be 14 feet 9 inches; and that it is to be fitted up as a coal winding and as a pumping shaft, being divided by a brattice of 3 inches in thickness, as shown in the annexed figure. Under such circumstances as the above, it would probably be considered advisable to sink, simultaneously, a companion pit near to the same situation, the water met with in the sinking being thus more readily dealt with, but the description of the processes observed in the principal pit will be sufficient for our present purpose.



The first consideration in the establishment of a winning is the nature of the road to it: and if the communication with the market for the coals is to be by railway, it will be found to facilitate matters much, if it can be made before breaking the ground, so that by its means the whole of the materials, machinery, timber, &c., required for the winning may be brought to the place. An arrangement to this effect will have very considerable results in lessening the outlay, the expense of carting forming a very large item, owing to the usually imperfect nature of country roads.

If however some miles of railway have to be formed, and it be of importance, as is most frequently the case, to have the colliery brought into operation as speedily as

possible, it will, notwithstanding what has been said above, be found necessary to commence sinking forthwith, and to have the railway and winning prosecuted simultaneously. If nothing can in consequence be brought by railway, some attention should be paid to the roads, in order that the carriage of materials may meet with as little impediment as may be.

Sinking is usually performed by contractors, who provide all labour, or whatever may in addition be specified and agreed upon, at a price per fathom which varies according to the circumstances of the case. The following may be taken as an example of the usual conditions for sinking an ordinary pit :—

1. The pit to be sunk to the depth of fathoms from the surface—viz., fathoms to the thill or floor of the seam of coal, the remaining fathoms being for sump.
2. To be feet in diameter when finished : the contractor to take out all extra space necessary for putting in timber, walling, or tubbing, wherever the same shall be required for securing the sides and keeping back water, without any extra price per fathom. The contractor also to put in all timber that may be so required free of charge.
3. Contractor to find all gunpowder, oakum, shot-paper, candles, cartridges, fuse, and sinkers' flannels, the owners only providing ropes, kibbles, corves, tubs, gear and sharping the same, timber, and nails.
4. Contractor to sink the pit with a jack-engine to be erected by the owners, and to keep the pit free from water during the time of actual sinking, timbering, and contract work, unless the water should exceed thirty 60-gallon tubs per hour.
5. The pit to be divided by a temporary brattice, composed of buntons and deals, leaving a clear space of feet for ventilation. The buntons to consist of Memel planks and battens placed alternately, 3 feet apart centre and centre, and properly secured to the shaft at the ends, the stringing planks into which they are to be inserted being spiked to wooden plugs driven into holes drilled into the wall sides at least 12 inches for the purpose. The buntons to be clad on the foreside with inch deals of suitable lengths and breadths, planed so as to make an airtight brattice, and nailed to each bunton with two good hammered pit single tack nails. This brattice to be carried down regularly with the sinking of the pit, so as to keep the bottom at all times well ventilated, Where the shaft is lined with metal tubbing, the stringing planks to be firmly spiked to the joints of the tubbing.

The object in having the alternate buntons of Memel plank is to allow of their application to the permanent purpose of forming the guide buntons when the time has arrived for fitting up the shaft with cages, &c., and with this view the position of the temporary brattice must be determined.

6. The contractor to find and provide all labour except enginemen and firemen's wages, and the preparation of cribs and other timber.
7. No shots to be put in within 12 inches of the wall side, withont the viewer's express leave : the whole of the shaft being properly dressed down with hacks.

This is only necessary when it is expected that the strata passed through will be sufficiently firm to dispense with walling. It will, however, as a general rule, be found to produce a far more satisfactory result to have shafts (where not lined with metal tubbing) walled from top to bottom, in which case this clause may be considerably modified.

8. The contractor to finish the work to the satisfaction of the viewer, who shall at all times have access to inspect the work: the sinking and other necessary operations to be continued by the contractor from one o'clock on Monday morning until eleven o'clock on Saturday night, such a number of men being continually employed in the bottom of the pit, or elsewhere, as shall in the opinion of the viewer be adequate to the due performance of the work.
9. The contractor to discharge any man of bad character, or who shall be considered incompetent, if required to do so by the owners or viewer.
10. If the sinkers are required for any shift work in the shaft, to be paid   per shift of four hours: and if required for any other purposes, such as lowering pumps, &c., to be paid   per shift of eight hours. The above shift wages to be paid by the owners.
11. The contractor to make out fortnightly, on the measuring day, and deliver at the colliery office, an accurate account of the strata passed through during the fortnight, together with average specimens of the same.
12. The work to be measured or estimated by the viewer every fortnight on the   , and the contractor to be paid on the   following, less ten per cent. to be kept in hand until the work is completed.

The conditions, besides the above, may embrace any other description of work, or manner of doing it, at the option of the viewer, who will do well to have invariably a clearly expressed understanding with the contractor on all points, before the work is commenced, as the absence of such often leads to disagreements, which might easily have been avoided.

It is sometimes, however, preferred to do the whole of the work by days' work, or shift, a master sinker being appointed by the viewer, to constantly superintend the work, in order to see that it is properly done and no time lost.

In this case one of the workmen in each shift is placed in charge of the shift, for which he receives a little extra pay: and it is his duty to see that the instructions of the master sinker are attended to in his absence.

In sinking a pit through such strata as have been above described, the probability is that several contracts will have to be made.

The first will be for sinking through the clay to the stone head.

The second for sinking in the limestone until the water is met with.

The third for sinking through limestone with water.

The sinking through the sand beneath the limestone will not be done by contract, but by shift or days' work.

The fourth contract will probably sink the pit through the coal to the bottom of the sump.

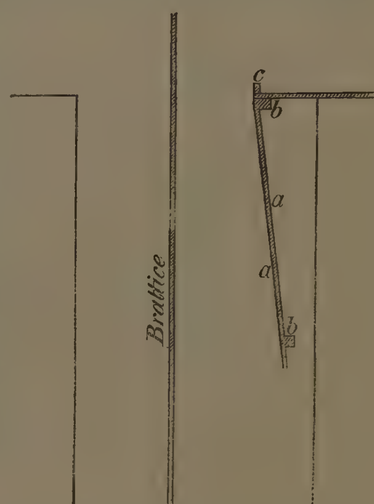
The main features of each separate contract will be in accordance with the form of contract given above.

Previous to commencing to sink, it is necessary to have in readiness a stock of sinking corves, or kibbles, hacks, drills, malls, wedges, and shovels, &c. (Plate 36.)

1. Sinking Corves (fig. 1.) should be made of well-seasoned hazel, and of the capacity of 10 pecks: care must be taken in making them to have the bottom of the corf bows well secured by washer and cotteril, so that there may be no chance of their drawing out: the top of the bow should also stand high and angular, being just rounded within the angle to receive the hook: the reason being that should the ascending corf come in contact with the descending one, the bow may not only operate in warding it off, but also from the nature of the suspension from the hook, prevent the corf from being canted, and any stones thrown out into the pit, whereby the sinkers in the bottom of the pit might be killed, or seriously injured.

A round iron kibble of similar capacity to the sinking corf may be substituted for it with advantage, as with it not only the stones, but also a considerable quantity of water may be at the same time drawn out of the pit. Wooden kibbles or tubs are also sometimes used, but as they are made square, they are objectionable on account of the liability of their angles to come in contact as they meet in the shaft: they are therefore less safe than either corves or round iron kibbles, and on this account should not be adopted.

After the corf or kibble is brought up to the surface, or a little above it, it is drawn by the waiter-on or banksman towards a tram (fig. 2.), upon which by a reversed motion of the gin or engine, it is lowered: it is then replaced by an empty one. When this arrangement is adopted, the top of the pit is partially covered over, as shown in the diagram annexed, so as to allow the tram to be placed as near to the ropes as possible, the corf or kibble being prevented from catching the under edge of the covering by means of boards (*a*, *a*) called "striking deals," nailed diagonally to the front side of the cover and to a bunton (*b*) placed for the purpose, as shown. There is also a raised bead (*c*) fastened on the upper side of the front of the partial cover to prevent any tram or carriage from running into the pit, which possibility should be further prevented by all tramways or iron plates upon which the trams run, being so laid as to dip from the pit top.



The mode of landing the corves, &c., above described, prevails in the North of England, but is not adopted in most other districts, the plan there being to lay a rail on each side of the pit, and continue it back from the pit, 6 or 8 feet: the level of this rail being lower than that of the ordinary tramway by the height of a traveller which, after the corf or kibble is lifted above the pit top, is pushed over the pit, and the corf then lowered upon a tram placed upon it. The traveller has also an empty corf upon it, to which the hook is transferred from the full one. The empty corf

having been lifted off the traveller, the latter is drawn back from off the pit, and the tram with the full corf upon it, being on the level of the tramway, is pushed off the traveller on to the tramway, and taken along it to the rubbish tip. This latter plan is the safer of the two.

2. Hacks should be made of good tough iron of the length of 18 inches, and weigh 7 lbs. each (fig. 3). Much depends upon having these well sharped, and some skill is necessary to enable a blacksmith to do this properly: the points must be steeled: if they are not hard, they wear off instead of cutting a hard stone, and if they are very hard they are often at the same time brittle, and the points snap off. The hack shafts are made of sound tough ash, about 2 feet 6 inches long. There ought to be a good stock of hacks, so that as they become blunted they may at once be replaced by sharp ones.

3. Drills (fig. 4) ought to be made of the best iron: Swedish is preferable: they may also with advantage be made entirely of steel: they are used for drilling or boring holes into the stone for the insertion of gunpowder for the purpose of blasting. They are made of different lengths, varying from 18 inches to 4 feet, the different sizes being put in successively as the drilling proceeds. The cutting edge of the drills must be well steeled, and should be made for the 18 inch or first drill (*a*) 2 inches: for the 28 inch or second drill (*b*) $1\frac{3}{4}$ inches: for the 3 feet or third drill (*c*) $1\frac{1}{2}$ inches: and for the four feet drill or jumper chisel (*d*) $1\frac{1}{2}$ inches in breadth on the edge. The reason why drills should be made of the best iron, or of steel, is that by repeated beating on the head by the mall, if the iron is bad, it splits and turns over, and is thus liable to cut the hands of the workman who turns it, or is liable to give off dangerous splinters of iron from under the stroke, or to snap in pieces.

When it is intended to drill a hole, a place is marked off with a hack, and one man sits down holding the drill in both hands, between his legs, and another with a mall (fig. 5) strikes it repeatedly, the first man turning the drill round all the while. If the hole is in wet stone, means require to be used for keeping the powder dry, which are as follow: sometimes tin cartridges are used, which consist of cylinders made of a size suitable to contain a sufficient quantity of gunpowder, with a small tin stem to allow of its being ignited. When these cartridges are used, however, the powder is not by any means so effective as when it can be applied without their aid and most usually a paper cartridge, by being well greased, is found to answer the purpose. When the paper shot is used, in order as far as possible to keep the hole dry, the latter is filled with stiff clay, and a round bar with a hole near the top, called a bull (fig. 6) is driven in, the object being to fill up the chinks or crevices in the stone through which the water oozes, with the clay, in order to dam it back. After the bull has been driven in, it is carefully drawn out again by a cross bar (a common drill will do) put through the hole in the bull, which is for this purpose. The cartridge is then

placed upon the point of a pricker, which is thrust into it, and which is a taper piece of iron, pointed at one end and having a ring at the other (fig. 7), and then placed at the bottom of the hole: this being done, first a little oakum, and then small pieces of metal or shale are put in, and by means of a beater (fig. 8) and hammer (fig. 9), the hole is tightly stemmed or tamped up. The pricker is then steadily withdrawn, which leaves a porthole to allow the communication of fire to the powder, which is done by means of a straw of sufficient length filled with fine powder: a small piece of candle end (or match) is then attached to the straw by a piece of clay in such a position as that when flame is applied to the point of the wick, it may travel under and ignite the powder in the straw.

It is in some districts a common practice to use bags of tarred canvas instead of tin cartridges or greased paper shots in wet holes, and safety fuse instead of straws is coming more generally into use. For all operations of blasting, it is the safest and most effectual mode of communicating fire to the gunpowder.

The sinkers, with the exception of one, having been drawn away either out of the pit or to some place of safety, and the sinker in the bottom having ascertained by calling and receiving a reply that all is ready, applies a light to the match or fuse: shouts "bend away!" or something equivalent, and is rapidly drawn up the shaft. The gunpowder then, if all has been rightly managed, explodes, and blows up the stone as intended.

In a sinking pit it is scarcely possible, on account of the wetness, for the pricker point by coming in contact with sandstone or post at the bottom of the hole, to ignite the powder; if the stone is at all dry, ignition of the powder and consequent accident may arise from the use of an iron pricker: it is safest, therefore, to use prickers made of copper, and as a still greater precaution, copper beaters should be used as well. Tamping with *shale* or *metal* must also be strictly observed, especially when the hole is in rock; tamping with broken rock in a hole drilled in rock frequently produces sparks, and has often been the cause of accidents, by their ignition of the powder.

Latterly, gun cotton, nitro-glycerine, and dynamite, have been more or less extensively used in blasting operations, and have their respective advocates: the repeated serious accidents, however, which, even in practiced hands, have occurred in using these dangerous compounds, considered in connection with the too frequent accidents which take place with the comparatively harmless gunpowder, seem, so far at least to condemn their use for ordinary mining operations.

4. Wedges are, as their name implies, wedge-shaped pieces of iron 7 or 8 inches long, and tapered to a point. They are used for breaking to pieces large stones displaced by gunpowder, and for taking off that portion of stone next to the wall-sides of the pit, which ought not to be taken off by gunpowder; they are used by their points being placed in a small hole, made with a hack, and then driven in by a mall.

5. SINKING SHOVELS are of a pointed shape (fig. 10).

The corves or kibbles are suspended to the rope by a spring hook (fig. 11), which should be constantly examined, and the spring kept in perfect order.

After all the preliminary arrangements have been made, the sinking is commenced by marking off a circle on the ground 16 feet 9 inches in diameter, and with hack and shovel digging up and casting out the soil and clay to the depth of, say, 6 feet.

The centre of the pit, as commenced from, must be the centre of every part of the sinking: its position must be carefully preserved, and everything that is done, whether timbering, walling, or tubbing, must be true to this centre. This is of the utmost importance, and any deviation from it should admit of no excuse.

A crib, which ought properly to be made of oak, about 5½ inches square, and having an inside diameter of 15 feet 6 inches, is then sent down in segments (fig. 12), and put together on the bottom by the cleats being nailed on to the adjoining piece, and Scotch deals, 1 inch thick, are placed vertically behind it so as to pass down half of its thickness, the length of the deals being, say, 9 feet; these deals are placed close together, and are called backing deals. Another crib is then laid upon the first one, and after having been put together, is raised 3 feet above it, centre and centre, and supported by props, as shown in plate 37. A third crib is then laid upon the last, and raised in the same manner, and also a fourth, which will be as high as the top of the backing deals. Each crib must be supported by props placed upon that beneath. The timber being now 3 feet above the surface, will afford height for teeming the clay and rubbish which is got out of the pit until a foundation is obtained for the walling, by which it should be permanently secured. A temporary stage being erected upon the clay and timber, a jack-roll or single winch may be set, which will be sufficient to draw the rubbish until the water is met with at No. 3 on the section.

After the first timber described above has been set, the sinking will be recommenced in the bottom, and another fathom of clay taken out the sides of the pit being in a line with the *inside* of the first crib laid. After this has been done, the bottom must be shorn out to the full size of 16 feet 9 inches, and a crib laid on the bottom as at first: the clay must then be shorn out upwards: the backing deals must be put in behind this last, and the first crib laid: another crib, rested upon props, is to be put in between these two last cribs, and then another tier of props placed on this intermediate crib to support the cribs which were first put in.

If the sand, gravel, or clay is of a wet and disintegrated nature, it will be better to put two instead of only one intermediate crib in the second and third fathom.

During the time the clay is shorn out beneath the first crib laid (fourth from the top), unless means were used to prevent it, the top length of timber might slip down into the pit, and to prevent this it is usually hung by deals or battens, nailed on the inside, from the temporary stage above named. This process is continued until the stonehead is reached. If the clay should not stand well, instead of sinking 6 feet

each time before putting in more timber, it may be found convenient only to sink 4 feet before making all secure.

In some cases, however, instead of the surface clay, &c., being so easy to pass through, as in the case here described, it is found to occur not only of great thickness, but wet, or filled with sandy and incoherent partings, or containing beds of quicksand or sometimes of soft clay, like mud, and then is only sunk through with extreme difficulty, and by using much care.

A case of this kind occurred at Framwellgate Moor Colliery, near Durham, where 24 fathoms of alluvial cover, containing beds of quicksand, were passed through. Plate 2 shows a detailed section of this deposit, and Plate 38 exhibits the plan of proceeding. The diameter of the pit, where commenced, was about 30 feet, and the upper clay being dry, was passed through with ordinary timbering: the cribs were put in 6 inches square. Beneath the clay, however, greater difficulties were anticipated, and it was on this account that the pit was commenced of so large a size, the intention being to pile through the sand.

Accordingly, when the top of the sand was reached, other two cribs, each 6 inches square, were laid 3 inches inside of the two cribs at the bottom of the clay, and piles of fir, 6 × 3 inches in section, were driven between these two courses of cribs as far as their length or the nature of the sand would permit. After a course of piles had been driven all round the pit, the piles being levelled to the circle to allow them to be driven close together, the sinking inside of the piles was recommenced: and as the sand was drawn from the pit, cribs were laid within the piles about 6 inches from each other until the whole of the sand as far as the bottom of the piles was drawn out.

The next process was to lay down two other cribs, 6 inches less in diameter than the last, and to recommence piling, and so to continue until the bottom of the sand was reached.

The reduction of the size of the pit by each length of piling was about 18 inches, and after the stonehead was reached and the walling put in the net diameter of the pit was 14½ feet.

The following account of sinking a pit at Norwood, near Gateshead, through the "wash" of the river Team, already referred to (page 3) affords a very good illustration of the difficulty of passing through such deposits: the pit is 20 yards from the river side:—

September 13th, 1851.—Commenced sinking pit 13 feet 6 inches diameter inside of timber 14 feet 8 inches full size), and went on till eight o'clock at night, when a 10 feet length of timber was put in, which made 1 fathom below the surface and 4 feet outset.

September 15th.—Went 1 fathom: put in English elm cribs 6 × 4 inches in section, and 1½ feet apart, with 1 inch Scotch deals set close together round the shaft for backing deals. Four stringing planks 6½ × 2½ inches put into the shaft and spiked to the cribs.

September 16th to 23rd.—Sunk and timbered 1 fathom each day. Cribs 5 × 4 inches, and 18 inches apart.

September 23rd.—Sunk and timbered $1\frac{1}{2}$ fathom.

September 24th.—Sunk and timbered $1\frac{1}{2}$ fathom: cribs were now put in $11\frac{1}{4}$ inches apart, and the size of cribs 5×5 inches.

September 25th.—Pit sunk half a fathom, making $10\frac{1}{2}$ fathoms by two o'clock p.m., when on account of the heavy rain, the waiters-on and sinkers came away. At half-past four o'clock, the river having overflowed its banks about $2\frac{1}{2}$ feet, began to find its way into the pit; and at six o'clock, there were 18 feet of water in the bottom. The sinkers commenced puddling clay round the top of the pit, and drawing the water out, which was reduced to 12 feet by nine o'clock. They re-commenced drawing water on Friday morning at two o'clock, when the water had again risen to 18 feet, from having passed through the clay. It was all got out by eight o'clock in the morning, when sinking re-commenced, and 1 fathom of loamy clay, with beds of sand from 1 to 3 inches thick was passed through.

September 27th.—Pit sunk and timbered 1 fathom.

September 29th.— Do. $\frac{1}{2}$ fathom, clay swelling very much.

September 30th.— Do. 1 foot, do. do.

October 1st.—Put in other four stringing battens, all the way down the shaft: Norway battens 20 feet by $6\frac{1}{2} \times 2\frac{1}{2}$ inches.

October 2nd.—Owing to the continued pressure of the clay and sand against the cribs, several of them broke, and at ten o'clock a.m. the sinkers had to come out of the bottom, when 2 fathoms broke away between 8 and 10 fathoms down, several of the others being thrust much out of shape, and having every appearance of instantly giving way. At eleven o'clock commenced filling the pit with ashes, and at five o'clock p.m. the top of the ashes was 35 feet 8 inches from the surface.

October 3rd.—Removed clay from the top of the pit to lighten the pressure.

October 4th.—Continued removing clay.

October 6th.—Sinkers commenced doubling cribs from the surface, the cribs being now 6 inches apart: size of cribs 5×5 inches.

October 6th to 11th.—Do. do. do.

October 11th.— Do. do. do., and put two balks across the top of the shaft (Plate 37*d*) to suspend the cribs from by four double iron chains: balks 45 feet long, by 13×13 inches. These balks were supported at each end of the shaft upon a square pile of sleepers 9 feet long by 10×5 inches, the chains being fastened to the cribs by clams made of $\frac{3}{4}$ inch square iron, and with spikes 6 inches long made of iron $\frac{5}{8}$ths of an inch square.

October 13th.—Commenced at midnight to take out ashes and double the cribs: at 6 fathoms from the surface, cribs put in 4 inches apart: at $6\frac{1}{2}$ fathoms, put in 2 inches apart: clay and ashes got out to $6\frac{1}{2}$ fathoms.

October 14th.—Four men busy puddling clay round the pit to keep out the tide: clay and ashes got out to the depth of 7 fathoms 3 feet 8 inches.

October 15th.—Put in cribs 6×6 inches, 1 inch apart, sinkers continuing to take out ashes: found the old cribs squeezed to within 18 inches of each other; clay and ashes taken out to the depth of 8 fathoms; also clay puddled round top of shaft.

October 16th.—Clay again began to spunge out at the sides of the pit as the sinkers cut it out: this continued all day.

October 17th.—Clay and ashes got out to the depth of 9 fathoms.

October 18th.—Clay and ashes got out to the bottom of the broken cribs at 10 fathoms: Norway battens nailed round the pit, and commenced (as the cribs above began to give signs of weakness) at 20 feet from the surface to put in another course of cribs inside of the battens: these cribs were put in 6×6 inches of oak, and 2 feet 7 inches apart, and at the bottom three inside cribs were put in, thus diminishing the size of the pit inside the timber to 12 feet, at which size sinking was continued.

October 19th.—Finished putting in cribs at eight o'clock a.m., putting in five cribs and one length of battens.

October 20th.—Put in seven more cribs inside of the battens up the shaft, and hung other four chains 16 fathoms long to suspend the cribs by.

October 21st.—Put in cribs close together: clay and ashes got out to the depth of 10 fathoms 1 foot. At this point the clay swelled so much that it was impossible to make ready for a length of timber with backing deals, however short (the last length or two had been 18 inches); and on

October 22nd.—The bottom of the pit was higher up than it was twelve hours previously, notwithstanding that the sinkers were sending out clay as fast as possible. It was therefore resolved merely to cut out the clay beneath the last length, at the sides of the pit first, and put in the crib in pieces without either cleats or backing deals, taking the clay out of the middle of the pit afterwards: surface settling down considerably: clay and ashes got out to 10 fathoms 3 feet.

October 23rd.—Clay and ashes got out to 11 fathoms.

October 24th,—Clay and ashes got out to 11½ fathoms.

October 25th.—Clay and ashes all out, and pit bottomed at 12 fathoms at six o'clock a.m. Pit sunk 3 feet: cribs put in 6 × 6 inches, close together.

October 26th.—Pit sunk 4 feet 10 inches: cribs put in close.

October 27th.—Pit down to 13½ fathoms: got a blower of firedamp in the clay, which filled a Davy lamp with flame 8 feet up the pit.

October 28th.—Pit down to 14½ fathoms.

October 29th.—Pit down to 14 fathoms 5 feet 8 inches in sand and gravel with water.

October 30th.—Pit down to 15 fathoms 3 feet, sand running a little.

October 31st.—Pit down to 16 fathoms 2 feet in sand and gravel.

November 1st.—At nine a.m. got soft blue metal at 17 fathoms.

These cases, though an exception to those generally met with, sometimes occur in flat districts through which rivers pass.

After reaching the stone-head, no time should be lost in getting the shaft secured either by walling it if the strata be dry, or by tubbing it if they be wet: for by the continued pressure against the back of the timbering, it begins to show weakness ere long, and when this is the case and the cribs begin to twist and break, the chances that the pit will close amount almost to a certainty. In fact, in nearly all cases of the closing of a pit in course of being put through such a deposit, it is preferable to remove the position of the sinking altogether 50 or 100 yards away, when this can be done, and commence anew from the surface with double or treble strength of timber, rather than to open out the closed pit, as in many instances it will be found that the latter method, even when successful, will be attended with more expense.

The actual cost of ordinary timbering through clay for a pit which, when finished, was 14 feet 9 inches in diameter, was as follows (1840) :—

	£	s.	d.
Backing deals, 52 feet 8 inches to a circle=316 feet to a fathom, at 14s. per 100 feet	2	4	2
Cribs $5\frac{1}{2}$ inches square, of Hamburgh oak, took 15 feet to a circle, which includes all waste, and 15 feet × 3s. 6d. × 2 ...	5	5	0
Lath deals, fourteen to a circle, 6×1 inches of Scotch fir=42 superficial feet per fathom, at $2\frac{1}{2}$d.	0	8	9
Punch props	0	0	10
Workmanship preparing backing deals	0	5	0
Sawing and making cribs 10s. each, including nails, cleats, &c. ...	1	0	0
Total cost per fathom	£9	3	9

This being the cost where there were only two cribs to the fathom, must be increased in proportion by the number of additional cribs put into the fathom.

After having sunk through and timbered the clay, and so much, if any, of the upper part of the magnesian limestone as will not stand alone, the diameter of the pit is to be brought in to its net size of 14 feet 9 inches, and sinking may be continued for a few feet, when, at the first sound stone, the wall sides must be shorn back until the diameter of the pit is 17 feet 3 inches; and this being the bed upon which the walling crib is to rest, it must be accurately levelled.

A large crib, which may be made of metal (Plate 37*f*) or oak is then laid upon some half-inch fir sheathing, placed upon this bed, and a packing of fir (*g*) 2 inches thick is put in vertically between the back of the crib and the pit wall, and some oak sheathing, tapering from $1\frac{1}{8}$ inch at the back to $\frac{3}{4}$ inch at the front, is placed between the joints. The size of the crib, which will of course have an inside diameter when wedged of 14 feet 9 inches, may be 13 inches in the bed; $6\frac{1}{2}$ inches high: if made of metal, it may be $\frac{3}{4}$ inch thick, and open at the fore-side.

A prop or stay being placed upon each joint and against the wall of the pit, to prevent the crib from rising during the wedging, the packing at the back of the crib is wedged until no more wedges can be driven in.

In putting in walling a cradle is required, which is a circular stage about 6 inches less in diameter than the net size of the pit: it may be made of three planks, 11 × 3 inches, covered across with boards 2 inches in thickness: towards the end of each plank a bolt with a plate and nut at the bottom and a ring at the top passes through, by which the cradle is attached by means of chains to the two cradle ropes, which are 7 inches in circumference, and may be raised or lowered by two double-powered winches, one set at each side of the pit top. Afterwards, the suspension of the cradle may be conducted in the same manner, or by a single 10 inch rope and crab.

Shafts may be either walled with ashlar stone or brick. If with stone, the stones should be dressed true to the circle, both on the face, beds, and joints: they should

be free from all imperfections: they ought not to be less than 9 inches in the bed, and 8 inches at the joint; and must be well set in good lime. In putting in the walling, the timber ought to be carefully taken out, and behind the walling the spaces should be filled and firmly beaten up with clay.

The following was the cost of walling in the pit already referred to:—

				£	s.	d.
278 superficial feet of freestone per fathom: stones 9 inches in the bed, and not less than 8 inches at the joint: price delivered 7d. per superficial foot, as measured in the pit				8	2	2
Dressing, at 3d. per running foot, and assuming eight courses to the fathom				4	15	8
SETTING—						
1 charge man 3 shifts (8 hours) at 3s. 8d. ...	£0	11	0			
3 sinkers 3 shifts „ at 3s. 6d. ...	1	11	6			
2 waiters-on 2 shifts (12 hours) at 3s. ...	0	12	0			
2 masons at bottom 3 shifts (8 hours) at 4s. ...	1	4	0			
1 gin-driver 2 shifts (12 hours) at 1s. 6d. ...	0	3	0			
Candles at night, 2lbs., at 7d. per lb. ...	0	1	2			
	£4	13	8			
9 feet of walling were put in for the above=per fathom				3	2	5
Total cost per fathom				£15	17	3

Walling with bricks is however sufficient in most cases, and is very much cheaper: the bricks should be made taper so as to correspond with the circle of the pit: in many cases the bricks may be manufactured on the spot out of the clay necessarily excavated in the formation of necessary reservoirs.

An excellent, though more expensive, walling material is also made with fireclay, a convenient size for the blocks being 24 inches by 9 × 6 inches.

During the time in which the walling is being put in, a horse gin (Plate 39, fig. 1), or preferably a small steam engine, which on account of its future application to underground haulage may be 20-horse power, and similar to the drum engine hereafter described, must be put up for the purpose of drawing the stones and water until the permanent machinery can be got ready; and at the same time the engine houses, boiler seats, chimneys, and shops, &c., should be set out, and proceeded with, with all dispatch.

The pulley frames and shearlegs (Plate 39, fig. 2) may now be erected: the height of the pulley frames to be 60 feet, and the shearlegs 72 feet: the pulley frames should be made of pitch pine, or of some other clean, straight, and resinous wood, 16 inches square, and the shearlegs, also, of similar size, with two fish pieces on each leg 40 feet long, 6 inches thick at the bottom, and 3 inches at the top, and 15 inches broad, the whole being bolted together with 1 inch round bolts passing through the fish pieces and legs.

Pulley frames are also sometimes constructed of iron, Plate 40 being an illustration of a good form: they are exceedingly light looking and strong, and not much more expensive than those made of timber. They have not as yet been many years in use, but there does not, so far, appear to be any objection against them. These frames were erected by Messrs. Green and Holland at their Tyldesley Colliery, near Wigan, about five years ago: their weight is 5 tons: the depth of the pit is 82½ fathoms: the working load upon the pulleys is nearly 2 tons: the time occupied in winding 20 seconds: and during the time of drawing, they do not exhibit the least vibration.

Previous to the application of the heavy machinery, the water is drawn by the small engine before alluded to, in iron tubs of the capacity of 100 gallons each: if a gin only is used, the tubs must of course be of smaller size, say 30 gallons. These tubs are of rather peculiar construction (Plate 36, fig. 13): they are in the form of a barrel, the bow by which they are hooked passing down to a point on the outside rather more than half way down, where the axle is fastened to the tub; the correct principle being to have the centre of gravity of the tub when full of water a little above, and when empty, a little below the axis on which it is turned: there is also another and smaller bow to each tub, which passes freely beneath the bow first mentioned, and is fastened to the top of the tub. At one side of the tub, adjoining the moveable bow, is a spring catch, which, when the tub is travelling in the shaft, attaches the tub to the bow, but which on being pressed back by the waiter-on at the surface, allows him by means of the fixed bow to pull over the tub, and empty it into a cistern, from the bottom of which the water is conducted away by a pipe or box: after emptying it, he pushes it back, when the catch springing into its place secures the tub in a vertical position, in which it is again sent down the shaft to be re-filled.

As the sinking progresses, the water will be found to increase in the stratum of magnesian limestone: it will be best to stop back by metal tubbing all the water that we possibly can as we descend, and as soon as a good foundation is met with we may put into the shaft a column of metal tubbing to reach up as far as the wedging crib underneath the walling already described.

A few feet beneath this crib, the pit is laid out to the necessary size for metal tubbing, viz., 16 feet 3 inches, and continued of this diameter until the position is approached where it is desirable to lay the wedging crib for the metal tubbing. The pit is then to be brought in to its net size of 14 feet 9 inches, or better, about 4 inches less, and sunk that size until a good sound piece of limestone is met with on which to lay the crib. The pit is then continued about 6 feet deeper, to allow the tub to dip and fill itself beneath the scaffold which is laid a little below the level of the intended bed. The wall-sides of the pit are then carefully shorn back with hacks, so as to cut out a level bed for the crib. When the stone is very hard, steel points driven by a heavy mall are found to be very effective.

The full diameter of the crib bed may be 17 feet 3 inches, which allows 16 feet 11 inches for the crib, which is 13 inches in the bed, 6½ inches high, and closed at both front and back.

The following is a very particular account of the cost of putting in a wedging crib in magnesian limestone in the year 1841 :—

This wedging crib was laid at the depth of 51 fathoms from the top of the outset, which was 8 feet 3 inches above the surface, commenced at 50 fathoms to reduce the pit gradually from 16 feet 3 inches to 14 feet 4 inches, and then sunk down 4½ feet below the most likely point for the crib bed, so that the water tubs might dip themselves: the water was eighteen 150-gallon tubs per hour: after the tubbing was wedged, the water was half a tub per hour.

A scaffold was then laid, and the pit walls shorn down until the crib bed was reached. The principal point to be attended to is to have the back sound and good, and if this be the case, there is no fear of carrying the water. After getting the crib bed properly levelled, laying the crib was commenced: the crib consisted of 10 segments, 14 inches in the bed at the under side, and 13¾ inches in the bed at the upper side, having a hang of ¼ inch to prevent the crib from rising during the wedging: there was also a prop or stay placed upon each joint for the same purpose. Each segment had two holes in it at the under side for letting out the air in casting: the height of the crib was 6½ inches, close at front and back, and the thickness of metal was 1¼ inch. English oak sheathing, tapered from 1¼ to ¾ inch, was put in between the joints, and some American fir sheathing, half an inch thick, was laid upon the crib bed for the crib to rest on: there are 2 inches of packing between the crib and wall. The diameter of the crib, as laid down, was 14 feet 11 inches; and after being wedged, 14 feet 9½ inches. It took seven courses of 6 inch wedges, five courses of 4 inch wedges; one tier of spiling (half wedges) and one course of iron wedges.

The expense of forming the crib bed and wedging the crib, including the cost of the crib, wedges, &c., was as folllows :—

	£	s.	d.
Shearing down the bed, including all expense of sinkers (9 men in the bottom), waiters-on, and hack carriers: took 122 hours: stone very hard	32	2	6
Laying crib, putting in packing, and making ready for wedging...	2	6	6
Wedging: 10 men in a shift, including waiters-on and hack carriers (35 hours)	10	4	11
Packing: Memel 2 inches thick and 6½ inches high=28 feet of 2 inch plank at 5d. per foot	0	11	8
3,030 6-inch wedges: 2,160 4-inch wedges, and 490 spiles=70 feet of Memel plank at 7½d. per foot	2	3	9
Making wedges: 5,435 at 7d. per hundred	1	11	8
290 iron wedges laid angleways=36 lbs. at 1¼d. per lb.... ...	0	3	9
Bottom sheathing for crib to rest on=63 superficial feet of American fir at 1½d. per foot	0	7	10
Carried forward	£49	12	7

	£	s.	d.
Brought forward	49	12	7
Joint sheathing of English oak: took 10 pieces=1 foot	0	4	6
Should the crib approach to its net size sooner than expected, an iron wedge is driven into the joint sheathing.			
Crib, 10 segments each, weighing 7 cwt. 1 qr. 17 lb.=74 cwt. 0 qr. 2 lb., at 6s. 9d.	24	1?	7
Laying out for tubbing size below the crib, and cleaning out bottom for contractor to commence sinking	11	19	7
Entire cost	£86	16	3

The last item of cost is not incurred until after the metal tubbing has been put in upon the crib, and the wedging finished.

After the wedging crib has been wedged until it is no further practicable to drive in any more wedges, the setting of the tubbing is commenced with as follows:—

It is very improbable that it will be necessary in practice to put in so short a column of tubbing so near the surface as shown in Plate 37: should it be so, it will not be necessary to have the tubbing more than half an inch in thickness, and the height of the segments may be 24 inches (Plate 39, fig. 3).

All the tubbing, before being put in, should be well tested by punching it at all its edges, to ascertain that the metal is sound and free from honey-comb: and it is also necessary that the iron founder should use the greatest care in casting, so as to insure that the thicker part round the centre hole, where the metal is thickest, shall be sound. I have examined tubbing which had failed, and have only been able to attribute the failure to this cause, the metal about the boss being in many cases quite hollow in the middle, and without any external appearance of the defect.

Fir sheathing in the first place is laid upon the wedging crib, the thickness of the sheathing being $\frac{1}{2}$ inch and its breadth $4\frac{1}{2}$ inches, and a course of tubbing set upon it round the pit.

As is shown in the plate, there is a flange at the back of the top, and also at the back of one edge of each segment, of the depth of about an inch, the object being to keep the sheathing and adjoining segments in their places; and it is well to have a similar flange or bracket cast upon the top of the wedging crib, so as to prevent either the bottom sheathing or bottom course of segments from being driven back on the crib.

The first course of tubbing being set, and similar fir sheathing to that described being placed between the vertical joints, pieces of wood are put behind the joints of the segments, between the tubbing and the wall-side: these pieces consist of what are termed baff-ends, which are about an inch thick, and spares, which are baff-ends roughly thinned towards one end, like a wedge, by means of which, driven between the baff-ends, the tubbing is secured firmly in its place. Upon this first course sheathing is again laid: another course of tubbing is set upon it, and in this manner, backing up the empty space behind with soil, &c., the whole is proceeded with up to

the stone which was left under the wedging crib where the walling was put in. This stone is then taken out of size sufficient for the tubbing, which still leaves sufficient support for the crib; and the whole of the tubbing having been put in, care being taken all the way up to equally break the joints, the wedging is commenced, and wedges of fir are driven into the sheathing as long as they can be entered.

Putting in the tubbing, and wedging the same, is all performed with the cradle.

The most convenient and safest way of lowering the tubbing segments is to suspend them by means of a stirrup with two holes at the bottom, one smooth and the other screwed, the length of the stirrup being such as to allow the holes on each side to be opposite to the centre hole of the segment; when by passing a bolt through the stirrup and segment, and screwing it, the segment is made perfectly secure, and can be easily set upon its place before removing the stirrup.

The following account shows the cost of putting in a fathom of metal tubbing in the same pit alluded to: the thickness of the tubbing was 15-16ths inch:—

				£	s.	d.
This tubbing consisted of 10 segments to a circle, each weighing 4 cwt. 1 qr. 12 lb.; and being 18 inches high, there were four courses to the fathom = 171 cwt. 1 qr. 20 lb., at 6s. 9d. per cwt.				57	17	1
Painting tubbing two coats on foreside = 31 yards, at 6d.				0	15	6
264 pieces of bottom sheathing, and 80 pieces of end sheathing ½ inch thick = 96½ super. feet of American fir, at 1½d. per foot				0	12	0
Workmanship making sheathing				0	1	6
3 spares and 2 baff-ends to each segment = 240 square feet of 1 inch Scotch fir, at 14s. per hundred feet				1	13	7
(Baff-ends 1½ feet long; spares 6 to 8 inches, sharpened at side next wall, and each 6 inches broad.)						
Making spares and sawing off baff-ends				0	7	0
Laying tubbing ready for contractors				0	2	6
Backing with soil, limestone marl, &c.				0	4	0
Wedges: took 3 wedges to an inch, or 8,856 wedges per fathom = 80 feet of Memel plank, at 7½d.				2	10	0
Making 8,856 wedges, at 5d. per hundred				1	16	11
(These wedges were 4½ inches long: 1½ inches broad at the top, and half an inch thick.)						
PUTTING IN AND WEDGING TUBBING.						
1. PUTTING IN.						
4 men in bottom, viz., 1 chargeman and 3 sinkers, and 3 men at bank for bringing the tubbing to the pit; also soil, &c., from where the same was laid, being in as convenient a place as possible. The contractor paid the foregoing 6 men 2s. per shift of four hours, who put in three courses in four hours, or 1 fathom in 5·4 hours. The contract price was	£1	1	3			
Carried forward	£1	1	6	£66	0	1

		£	s.	d.	£	s.	d.
	Brought forward	1	1	6	66	0	1
2. Wedging. 11 men in bottom, viz., 1 chargeman and 10 sinkers; the tubbing was wedged twice in going up, and a third time in going down again—until, in fact, it was perfectly tight: it took one man constantly to send away the water tub through the hole in the cradle. The third course of wedging is angled, so as both to lift and thrust. The above men wedged $2\frac{1}{2}$th courses thrice in four hours, or 1 fathom in $7\frac{1}{5}$th hours, so that it took $12\frac{1}{2}$ hours to put in and wedge 1 fathom of this metal tubbing. The contract price was		2	3	6			
					3	5	0
					£69	5	1
Deduct $\frac{1}{2}$ inch sheathing for four courses = 2 inches, or 1-36th part of cost of metal for 1 fathom					1	12	2
	Cost of 1 fathom				£67	12	11

In Somersetshire, where the diameter of the pits has been small, it has been the custom to wall back the water of the new red sandstone. The stone usually employed is obtained from the lias, and the mode of proceeding is as follows :—

The diameter of the shaft where the walling is to be placed, is enlarged by 5 feet, so as to allow of $2\frac{1}{2}$ feet of "waterwork" being put in, and at the bottom a watertight wedging crib is laid as above described, oak being usually employed. The walling consists of a facing of walling stones properly dressed; and rubble stones and hot lime made from the brown lias limestone, which is eminently hydraulic, are carefully laid between the back of the walling and the shaft side. A box open into the pit at the bottom is carried up behind the walling to allow the water to get away, until the work is sufficiently set to be subjected to the pressure. The diameter of such shafts when finished has not usually exceeded 4 or 5 feet, but the walling has completely kept back the water under a pressure of 30 fathoms. I have had occasion to take out some of this work in order to enlarge the pits, and have found the walling a solid mass, the cement being as hard as the stone.

The following description of different varieties of tubbing, which have been adopted in the North of England previous to the application of that of metal, is extracted from the late Mr. Dunn's Treatise on the Winning and Working of Collieries.

1. Plank Tubbing was used in the sinking of Hebburn and other deep collieries about the year 1790. It was constructed as follows: the shaft was first widened for the length of the intended tub, if not already anticipated in the sinking. The ledge upon which the two foundation wedging cribs were intended to rest, and upon which the tub was to be built, was first levelled and polished with great care, its surface also

being covered with flannel and white lead, or some other such substance. This preparation being ready, the first wedging cribs were laid, consisting of the best oak cut into segments, and 8 or 9 inches broad, each joint being lined with thin deal placed edgways for the purpose of wedging. The cribs were then wedged throughout every joint as well as between them, and also the space between the cribs and the rock, the whole being wedged with wood so long as a chisel would enter. Next followed the ordinary spiking cribs of similar dimensions, adjusted by a centre line to the same range, being of similar length, but not so broad, and placed at intervals of from 18 to 30 inches, according to the expected pressure. These cribs were wedged sufficiently to sustain them firmly in their places, to abide the spiking which was to attach them to the planking which constituted the tubs, and which usually consisted of 2½ or 3 inch deals applied in lengths of 10 or 12 feet, being first well planed and bevelled to the circle of the shaft, after which they were fastened to the cribs with iron spikes.

2. Crib or Solid Tubbing.—The labour in constructing, and the difficulty of insuring tightness in the plank tubbing, led to the introduction of solid wood tubbing, which possessed the advantage of having neither planks nor spikes, and, therefore, when once tight and of sufficient strength, no incident could arise to produce leakage, whilst at the same time it presented a smooth circular surface for the general purposes of coal drawing.

The foundation of the wedging crib is prepared in the same manner as that above described: this is then succeeded by segments of wood 6 or 8 inches square, of elm or oak, prepared in indefinite lengths, and retaining between each joint, whether horizontal or vertical, a lining of endways-slit deal. These courses, so prepared, are built or walled upon each other, and carefully adjusted to the centre of the shaft by a hanging line. As the building proceeds upwards, the space between each crib and the rock is carefully packed with small coal or other soft material, so as to maintain the cribs steadily in their position. The building finished, it is surmounted by the ordinary stone walling before described, and the successive wedgings take place in the sheathing so long as any leakage appears, the wedges used for this purpose being clean fir, well seasoned, an iron chisel being used to perforate the wood, the better to introduce the wedges. In case of faulty cribs giving way by severe wedging, they are cut out and replaced by sound ones.

The wedging completed and the roughness adzed off, the shaft so constructed forms a perfect cylinder, and it is not uncommon to see a tub of this description sustain a pressure of 50 fathoms of water, or 150 lbs. to the square inch. This tubbing is incomparably more safe and durable than the plank tubbing, especially in collieries where the water is corrosive: indeed, under such circumstances, it is preferable to metal tubbing.

In sinking the C pit at Wallsend, near Newcastle, about the year 1786, a feeder of water of about 1,700 gallons per minute was met with at the depth of 30 fathoms

from the surface: this water was stopped by a solid wedging of crib upon crib. The cribs were of oak, 9 inches in the bed, with ½ inch fir sheathing between each joint.

It frequently happens that a detached piece of tubbing requires to be inserted into a portion of the shaft, apart from the walling, in which case the shaft is widened for the required length, and the top and bottom are squared and levelled for the reception of the two wedging cribs.

In Belgium and in the north of France the tubbing (cuvelage) is constructed of pieces of oak, which are formed so as that when piled up they may form a polygonal shaft of 10, 12, or 15 sides, according to the diameter of the pit. The vertical height of each course varies from 9·84 to 19·68 inches, depending upon the size of the trees from which it is taken: as regards the thickness, it ought to vary with the pressure of the water, and consequently with the depth where the tubbing is placed. The rule followed in the department of Nord (France), and founded on experience, is as follows:

From 0·00 fathoms	to 8·20 fathoms of depth	... ...	4·334 inches.
„ 8·20 „	to 16·40 „ „	... ...	4·724 „
„ 16·40 „	to 18·27 „ „	... ...	5·118 „
„ 21·87 „	to 27·34 „ „	... ...	5·512 „
„ 27·34 „	to 30·07 „ „	... ...	5·905 „
„ 30·07 „	to 32·81 „ „	... ...	6·299 „

—(Combe's Traité de l'Exploitation.)

In estimating the thickness of metal tubbing required to resist any pressure of water, it is necessary to take into consideration the diameter of the pit, and the vertical depth of the water pressing against the tubbing. If castings could be made perfect, of any required thickness, the thickness would be simply in proportion to the pressure multiplied by the diameter: the contrary, however, being the case, it is necessary to add to each calculated thickness a constant, and it will be found that the following formula gives results which may in practice be safely relied on, the height of segment being 2 feet:—

Let x=the required thickness in feet.
P=the pressure or vertical depth in feet.
D=the diameter of the pit, also in feet.

$$\text{then } x = \cdot 03 + \frac{P \times D}{50{,}000}$$

whence for various sized pits we have, at different depths, the thicknesses as under:—

DEPTHS.	10 FEET DIAMETER.	11 FEET DIAMETER.	12 FEET DIAMETER.	13 FEET DIAMETER.	14 FEET DIAMETER.	15 FEET DIAMETER.
	INCHES.	INCHES.	INCHES.	INCHES.	INCHES.	INCHES.
10 fathoms	·504	·518	·532	·547	·561	·576
20 „	·648	·676	·705	·734	·763	·792
30 „	·792	·835	·878	·921	·964	1·008
40 „	·936	·993	1·051	1·108	1·166	1·224
50 „	1·080	1·152	1·224	1·296	1·368	1·440
60 „	1·224	1·310	1·396	1·483	1·570	1·656

It is necessary in upcast shafts, where mines are ventilated by a furnace, or where there are underground engine fires, to guard the metal tubbing against the destruction occasioned by the sulphurous acid produced during the combustion of the coal, which being absorbed by the moisture of the shaft and trickling down the tubbing, corrodes it in a most remarkable manner, almost entirely, in fact, separating the iron from the carbon, and rendering the metal so soft that it may be easily cut with a knife. The trouble and expense occasioned by this circumstance are often very great, and serious accidents might possibly be the result; for supposing a segment of tubbing to be so weakened as no longer to be able to withstand the pressure, we have in the first place the probability of a large quantity of water being sent down the pit before the faulty segment can be replaced: and in the second, of the ventilating current being reversed, whereby the foul air of the goaves may be forced back into districts working with unprotected lights, to say nothing of the suffocating smoke and fumes of the furnace being forced back among the workmen.

Two methods may be adopted in order to preserve metal tubbing: either a lining of wood or brick may be placed next to it: if of wood, it may consist of deals 2 inches thick, properly bevelled to the sweep of the pit, and fastened by copper spikes driven into the sheathing, or plugs in the tubbing: if of brick, the bricks should be made of such a size and shape as to suit the size of the pit, and may be built upon the wedging cribs, the latter when the tubbing is put in being made 4 inches deeper in the bed, and the diameter within the tubbing being made 8 inches greater than the finished size of the pit, so that the net diameter required may be obtained inside of the brick-work.

The tubbing may also be made with inside bracketing, the bracketing facing the centre of the pit instead of being placed behind the tubbing, in which case the brick-work may be neatly placed within the brackets: this plan is, however, objectionable, as it is incompatible with severe wedging, and not entirely effecting the purpose intended, the edges of the brackets being exposed. By the mode above described the front of the cribs only will require protection. Any leakage will be more difficult to localise than it would be by the bracket plan, but such leakage would be far less likely to occur.

It has been found necessary in many instances, in close-topped tubbing, to put a pipe into one of the upper segments, which is either allowed to remain open and run as much water as it can, which may be conveyed to the pump or standage; or else the pipe is continued up the shaft as far as the level of the water behind the tubbing: the consequence of this not having been done has often been the bursting of the tubbing, a similar result having also followed the closing up of such pipe. Perhaps the principle of the hydraulic ram may in some degree explain this, as the sudden closing of the tubbing or pipe at once throws the pressure which is due to the column of water upon the tubbing with a certain velocity proportioned to the velocity of issue.

That some such cause as this is the correct one is apparent from the fact that when the water is outset to its level by a pipe, and the pressure laid gradually on the tubbing, as is observed by the water in the pipe gradually rising, no fracture or displacement of the tubbing takes place, notwithstanding that there is evidently (after the water has risen to its level) the same pressure on the front of the plug hole in which the pipe has been inserted, and opposed to that behind the tub, as if the hole were closed by a plug.

It is the opinion generally received that the gas contained in the strata is the cause of this, and that, unless it is allowed vent, it must have the effect of bursting the tubbing; but it is clear that since the tension of the gas must be equal to the pressure of the water under which it is generated, it cannot exert any greater pressure upon the tubbing than the water itself. It must be admitted, however, that the subject requires investigation, and as the insertion of the pipe has been founded on experience, it ought not to be neglected.

In the case of several wedging cribs, and separate pillars of tubbing, pipes have been taken from the top course of the under to the bottom course of the upper column throughout the whole: and although it is evident that the effect of this is to throw the pressure of the whole united column upon the lowest tubbing, yet when we consider that in all probability through lapse of time, the mean level of the whole will be the same, this is not productive ultimately of any undue pressure upon the tubbing.

Instead of the pipes above described, it is the practice of Mr. Coulson, of Durham, who has had very great experience in the sinking and tubbing of shafts, to have the wedging cribs made with a hole through them in the form of a valve seat, 3 or 4 inches in diameter, behind the tubbing, in which he places an accurately fitting valve: any pressure from beneath, by forcing up the valve, thus obtains the necessary relief.

It is probable that by the time the depth of 15 or 20 fathoms has been reached the ventilation will be faulty, and it will be therefore proper to adopt some artificial means of causing a circulation of air. An old method of effecting this consisted in having a box or spout 6 inches square internally to pass down the shaft, there being near the bottom another short spout at right angles to it: by pouring water down the inside of the spout, a certain quantity of air was carried down with it, which passed out of the short box, airing the bottom of the pit. This method was of course objectionable on two grounds: the first being that it was inefficient, and the next that it occasioned an addition to the quantity of water to be drawn to the surface.

Another plan consisted in having a box, say 12 inches square, made of inch deals, placed in the shaft, the ventilation through it being caused by a caphead at the surface, which being moveable upon a pivot, was, by means of a vane, kept always facing the wind. The ventilation by means of such a box may be improved, by substituting for the caphead a communication between the upper part of the box with a chimney; or with a small fan worked by hand.

In ordinary cases, however, especially when the pit is required to be of considerable depth, a brattice which consists of a wooden partition is usually put into the shaft, which, in consequence of the ample room which it affords to the descending and ascending currents, produces the desired effect. There is no reason why, under such circumstances, there ought to be a constant and uniform current of air in one direction; and it usually happens that extraneous circumstances, such for instance as change of wind, prevent any uniformity in the direction of a ventilation of this nature. All that is needed, however, is a tolerable circulation of air.

In our present case the brattice put in will only be a temporary one, to answer the purpose of ventilation during the sinking, and also during the period of making a communication between it and any other shaft or shafts by which the ventilation is ultimately intended to be carried on. A brattice of this description may be constructed in the following manner:—

Norway battens for side planks or stringing planks are taken of any length, 7 inches broad and $2\frac{1}{2}$ inches thick: they have at intervals of 3 feet, places prepared on one side to receive the ends of other battens which traverse the pit and are called buntons. The stringing planks having been spiked down the opposite side of the shaft, and the buntons secured in their places, Scotch or larch deals, 1 inch in thickness, and previously planed at the joints, are nailed securely upon the buntons, so as to make an airtight division.

For a more permanent brattice either one or other of the two following may be adopted:—

1. The Bunton brattice, which resembles that just described, put in more substantially. In this case the stringing should consist of 3 inch planks: the buntons the same, and the upright planks for the brattice should be 2 inches in thickness, properly slivered with oak.

2. The Plank brattice is, however, the best: it consists of 3 inch Memel planks, planed smooth at the edges, and built edgeways up plank upon plank, the planks being retained in their places by four stringing planks, viz., two at each end of the brattice planking, one of them being at each side of the brattice.

The brattice planks are kept secure either by iron dowells or oak slivers. The following was the cost, in 1840, of putting in the main brattice at the same pit already alluded to:—

	£	s.	d.
1. 7 planks to a fathom 11×3 inches by 14 feet 8 inches, at 7·3d. per foot	3	2	5
2. 21 dowells to a fathom, 6 inches long, of $\frac{3}{4}$ inch round iron = 16·8 lb., at 2d. per lb., including workmanship	0	2	10
3. Stringing consists of two 3 inch Memel planks on each side: 7 inches broad = 24 feet per fathom, at $4\frac{3}{4}$d.	0	9	6
Fitting up stringing	0	1	0
Carried forward	£3	15	9

	£	s.	d.
Brought forward	3	15	9
4. Planing planks, boring dowell holes, jointing one end of planks (the other being left for the sinkers to saw off), per fathom ...	0	3	0
5. Spikes for attaching stringing to pit wall, 10 inches long, 3 feet off each other, or 8 per fathom = 15·2 lbs., at 2½d. per lb. ...	0	3	2
6. Putting in brattice: 1 chargeman and 2 sinkers in bottom, and 2 men at bank for bringing planks to pit in each four hours shift: contract price	0	7	6
Cost per fathom	£4	9	5

Where tubbing is put in with the intention of putting in a plank brattice, it may be cast with grooves for the purpose of receiving the planks, thus saving the stringing.

The brattice may be put in to within about 4 fathoms of the bottom of the pit: if it is taken lower it will be damaged by the shots. It is also necessary to put, diagonally, a few deals from the bottom of the brattice to the wall side which is on that side of the brattice not used for winding, in order to prevent the corves or tubs from coming in contact with the bottom of the brattice as they are being drawn up the shaft.

The sinking may now be resumed in the limestone, in which, as we expect much water, the pit must be laid out as before of sufficient diameter to allow of more tubbing being put in. As the water increases, it will be found desirable to tub it back in accordance with the process described, until the fourth crib, with the pillar of tubbing resting on it, has been put in.

With the means laid down it may have been possible to attain this depth, but at this stage more powerful machinery will become necessary: this will consist of a pumping engine, or of a winding engine also adapted for pumping, or of both.

Pumping engines are constructed of various forms, but from these may be selected the following:—1. The Cornish engine (plate 41): 2. The Double-acting Beam engine (plate 42): 3. Barclay's patent pumping engine (plate 43): 4. The Direct-acting engine (plate 44): 5. The Lever or Crank engine (plates 45, 47, 48, 49, and 50).

Plate 46 is also a pumping engine, but not applicable until after the pit has been sunk, when it is placed underground, and will be further described hereafter.

1. The Cornish engine. In this engine the steam, which is used at high pressure, is admitted above the piston, the steam valve and the exhaustion valve being opened together. These engines are usually worked expansively, the steam being shut off at from one-sixth to one-third of the stroke. After the piston has made its full stroke, the exhaustion valve is closed, and another valve, called the equilibrium valve, placed in a communication between the upper and lower parts of the cylinder, is opened, which equalises the pressure upon each side of the piston, and allows the spears, which are heavier than the column of water, to descend and force the water up the pit. The Cornish engine has not hitherto been extensively used excepting in Cornwall. As regards the fuel consumed, it is most economically worked, but this perfection is more

probably due to the careful husbanding of the heat, viz., by jacketing the cylinder, clothing the steam pipes and boilers, and having ample boiler room, than to any peculiarity in the construction of the engine. The consumption of coal ought not to exceed $3\frac{1}{2}$ lbs. per hour per indicated horse power. The Cornish principle of pumping is now being adopted in extensive drainage of the drowned Tyne collieries now in progress. The principal engine, not yet at work (November, 1869), is of very large dimensions: I have been furnished with the principal dimensions and weights of the parts by Mr. J. B. Simpson, under whose management the works are conducted, from which I have made the following extracts. This engine (one of two to be placed in the same engine house) is built by the celebrated Hayle Foundry Company, Cornwall.

	Dimensions.			Weights.			
		Ft.	In.		Tons.	Cwts.	Qrs.
Cylinder	Diameter	8	4	Cylinder	13	0	0
	Stroke	11	0	Top and bottom, &c.	19	7	0
	Stroke in pit	11	0	Case	14	0	0
				Piston	5	16	2
Piston rod	Diameter	0	10	Piston rod	2	13	2
Main gudgeon ...	Diameter of bearing ...	1	7½	Main gudgeon ...	4	2	0
Main beam	Length	39	0	Main beam	40	0	0
	Between centres ...	36	0				
	Depth in middle ...	7	6				
	Two plates	0	4				

The entire weight of this engine is nearly 200 tons.

For a complete account of the Cornish engine, the reader is referred to a Treatise on the Cornish Engine, by Mr. William Pole; also to a work on the same subject by Mr. Thomas Wicksteed.

2. The most common form of engine, erected exclusively for pumping in the North of England coal mining district, is the double-acting condensing engine of Boulton and Watt, and which is applied in many different ways. In very deep winnings, the manner of applying the engine is represented in plate 42, in which care is required so to arrange the sets of pumps that the engine, whether in ascending or descending, shall have the same amount of work to perform. It is evident, however, that from the variety of movements made by the vertical and diagonal spears, this method of pumping cannot be considered as perfect. For moderate depths, the best plan probably is to have a staple sunk in the engine house, and the high set of pumps placed in it, attached either to the main beam, which may be prolonged over the cylinder, or to a lever beam between the cylinder and back wall of the engine house.

3. The third form of pumping engine referred to is a patent of Mr. Andrew Barclay, of Kilmarnock. In its general construction it is similar to a Cornish engine inverted: as compared with the Cornish engine, it involves a much less expensive description of engine house.

4. Plate 44 represents a direct-acting engine from the design of Mr. J. D. Leigh, of Patricroft: these engines have the advantage of cheapness as regards first cost: there is no reason why they should not be economically worked; but they have the disadvantage of covering up the pit top to an inconvenient extent.

5. The fifth form of engine which I shall describe is the crank or rotatory engine. This is well adapted for moderate depths, and large quantities of water, but whether equally so, when the depth is considerable, a little more experience will be necessary in order to determine, as the strain on the main shaft becomes a somewhat serious matter: this remark more especially, however, applies to engines connected as in plate 47; for when the pumping is arranged in the same manner as shown in plate 45, there is no extraordinary strain on the main shaft.

Pumping with the double-cylindered horizontal engine (plates 49 and 50) may either be performed by having bell cranks in the main shaft or by having the connection between the main shaft and pumping cranks made by means of spur gearing: there is an advantage in this last plan, that it allows the engine to be run at speed, with a moderate velocity in the pumps.

There is a great advantage in having a fly wheel attached to a pumping apparatus: in the case of all direct lifting engines the inertia of the load is not, as in the case of the crank engine, overcome gradually, but all at once, thus evidently incurring, under the same strength of materials, a much greater liability to rupture with the former than the latter. The strain upon the parts of a Cornish engine, on the sudden admission, through its large valve, of steam at a high pressure, is enormous.

The crank or rotatory engine also possesses the advantage of adaptation to both pumping and winding, as shown in the plates.

If, as will have been ascertained by the boring, the sand (lower new red sandstone) is soft, it will be necessary to lay out the pit under the fourth crib to such a diameter above the sand as to allow of piling being performed, as in the case of Framwellgate Moor, care being taken that the diameter at the bottom of the piles be sufficient to allow the full size of the pit to be preserved.

The sinking with pumps is conducted as follows:—The lowest pump or windbore (plate 51, fig. 1) being placed at the bottom of the pit immediately beneath the end of the beam, and the rest of the pumps, viz., the clack-piece (plate 50, fig. 2), the working barrel, bucket door-piece, common pumps and hogger-pump (plate 50, figs. 3, 4, 5, and 6) being placed vertically upon each other in this order by means of the crabs (plates 53 or 54), and temporarily steadied in the shaft, are collared to what are termed ground spears (plate 51, figs. 1*a* and 7), one on each side of the set, by means of iron collarings or hoops. The joints of all the pumps should be accurately faced, so as that their drawing together by the pump bolts should be sufficient to make a watertight joint.

At the top of each of the ground spears is one of a pair of 5 or 7-fold blocks, called ground blocks, the others being placed on buntons at the top of the pit. Through these blocks a pair of ropes are rove, the surface end of each being taken to a ground crab, which is of similar construction to the main or tail crab (plate 53). These ropes, which are called ground ropes, will of course vary in diameter with the weight of the set, but are usually 7 or 8 inches in circumference. After the set is properly placed, the spears (plate 51, fig. 7) are put in by the crabs, and attached to the engine. The clack (plate 51, fig. 8) is then put in its place: the bucket (which resembles the clack) is in the next place attached by means of the bucket sword (plate 51, fig. 9) to the bottom rod of the spears (plate 51, fig. 10); and the clack and bucket doors being screwed to their places, the engine may be set to work.

If at any time the water should overpower the engine, and rise above the bucket door, the bucket, when it requires changing, may, by means of the spears, be drawn up through the set of pumps, which ought to be an inch larger in diameter than the working barrel; but in order to change the clack, which also requires to be drawn to the top of the set, it is necessary to introduce the fish-head (plate 51, fig. 11) attached to the bottom of the spears, the spring catches of which (*a*, *a*) raise the clack by its bow (*b*, *b*) when passed through it and drawn up again.

At the bottom of the windbore are the hand-holes and snore-holes, the upper tier or two of which must be plugged up when the men are in the bottom, so that the water may not be too deep, but at the same time it must be borne in mind that sufficient water way must be allowed, otherwise the engine will be what is termed wiredrawn, and will not have the space beneath the bucket kept solid, which will occasion the weight upon the descending spears to be increased to such a degree as in all probability either to break them or damage the engine. Care must also be taken to prevent any chips or pieces of wood from getting to the snore-holes, as if they pass through they may get into the clack-falls, and stop the engine from pumping.

The engine should not be driven harder than is just necessary to keep down the water, otherwise it will be what is termed "working on air," and for a similar reason to that given above, liable to injury.

As the sinking progresses, the pumps are lowered by the ground crabs; and when the hogger pump is nearly down to the surface (or delivery drift), it is taken off by means of the main crab, and lifted over the top of the spear, which, to facilitate its detachment, is clammed to the front of a piece of wood called a Y, which, instead of the spear itself, is attached to the engine beam. Another common pump is then put upon the column, and the hogger pump replaced over all.

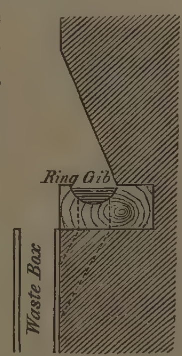
After the sand has been passed through, a good crib bed must be sought for, and upon it a wedging crib laid as already described; and for greater security another may be laid upon it (crib No. 5), and the tubbing built up as before, but strongly stowed behind between the back of the tubbing and the piles, and all tightly wedged.

Other modes have been successfully adopted of passing through such sand, among which may be named that adopted by Mr. John Taylor, at Ryhope Colliery, near Sunderland. In this case, instead of tubbing back the limestone feeders, they were pumped to the surface: by this treatment it was conceived that the sand, relieved from any hydraulic pressure from behind, would not burst into the pit: the result justified the expectation. The plan of lowering down a weighted caisson has also been successfully applied: the bottom of the caisson (put together in segments similar to those of cast metal tubbing, but with the flanges in the *inside* of the pit) having a cutting edge, and above it a broad flange, to allow of it being cased with masonry to add to the weight: this plan, however, is very liable to failure if the sand should contain boulders or hard concretions: the side of the caisson, where these exist, being checked in its downward movement, while the other is free, causing the caisson to cant.

After the tubbing has been placed in the shaft, and the brattice continued down, the sinking may be re-commenced and continued down to the depth of, say, 40 fathoms; the pumps being continued down in case of need: if they are still required, the sinking set having now attained a sufficient length, preparations must be made at this point for placing the permanent or standing set, which may be either a bucket or plunger set.

If a bucket set, the pumps and apparatus will be the same as already described. The set will stand in a cistern placed upon a strong support of either oak or iron, called a standing set bunton, as shown in plate 53, *k* and *l*, and in plate 55, fig. 1, *a* and *b*, the cistern having directed into it, by means of waste boxes, the water above, which is collected by the ring cribs placed in the shaft.

The ring cribs consist of cribs which are, where necessary, walled in with the walling in the shaft, having a gutter hollowed out in them on the shaft side: and the portion of the shaft wall immediately above being cut back, the whole as shown in the adjoining diagram, the water naturally follows down the shaft side and passes into the ring, and from the ring the water so collected is conducted down the waste box, as shown.



If, however, the plunger principle is adopted, the arrangement will be different: in this case, the column of pumps or pipes only will stand in the cistern, as shown in plate 52, there being a clack placed in *h* and another in *g*; the plunger piece (*d*) resting on the support (*f*) being also placed on the standing set bunton by the side of the cistern. The pump must, in every case, be properly secured by timber or iron collarings, to the side of the shaft.

The standing set cistern is also the receptacle of the water from the sinking set of pumps, which is lowered down by the ground crab and ground ropes as before; but

to save rope, the top blocks may be lowered down to the standing set bunton when convenient: and when the bottom of the pit has been reached, the pumps must be placed on a firm foundation, and collared to the shaft as above.

If the plunger system is adopted, it is better, instead of placing the plunger apparatus in the bottom, to have a short bucket set placed there, the bottom of the plunger set being kept higher up the pit, and placed upon a standing set bunton. The reason of this is that in the event of an accident by which the water rose some distance up the shaft, the plunger apparatus would be drowned, and inaccessible for purposes of packing, or of changing the clacks, if necessary; whereas in the bucket set, the working barrel and clack piece being some distance from the bottom, are much longer in being drowned, and even after being so, the bucket and clack can, by means of the spears and fish-head, be readily changed. The clacks in the plunger set might no doubt be changed through the pumps, as in the case of the bucket set, if the pumps and upper clack seat were made of sufficient size, but still the packing of the plunger could not be effected.

During the sinking, where the stone is not good, the shaft must be secured with timber, as above described, until in every case a good foundation for walling is obtained; so that, when finished, the shaft may present a perfect cylinder, secured either by brick or stone walling and metal tubbing from top to bottom, excepting where the standing set cisterns may be placed, and where the access is made into the workings.

In a shaft such as that described, it will not probably be desirable to put any tubbing nearer to the coal than 20 fathoms, as such water, if dammed back, would most likely find its way through joints of the strata into the seam, and be much more troublesome than in the shaft: besides, it would pass into the workings as the strata became broken in the course of extracting the coal, and would be to pump eventually.

During the sinking of the pit with the pumping engine, the erection of the winding engine (if not already provided for in the pumping engine itself), of which plates 45, 47 and 48, and 49 and 50 represent suitable forms, must be proceeded with.

Instead of permanently drawing the water with pumps, when the feeders are trifling and the depths great, it is unquestionably most advantageous and economical to draw the water by means of the winding engine and water tubs, and to dispense with pumping apparatus altogether. For this purpose the tubs may be made of similar size to the cages which traverse the shaft, closed at the sides and bottom, and fitted up with groove to work in the guides. These tubs should be pointed at the bottom to allow of their easy entrance into the water, and would be all the better for being pointed at the top also, so as to allow of their easy exit from it. They should be constructed with a valve at the bottom which opens as the tub descends into the water, and which by means of a catch placed at the surface, and acting upon a lever and rod connected with the valve, is again opened, and the water delivered previous

to the tub being again sent down the shaft. If the upper part of the water tub were pointed, as at the bottom, it would be necessary, in order to obtain the full value of the construction, to have a valve upon it opening outwards, in connection by a rod, with that at the bottom opening inwards. A feeder of water of 50 gallons per minute at the depth of 200 fathoms, which would require the constant action of an engine with an 8 inch working barrel and 6 feet stroke at 4 strokes per minute, could be drawn in five or six hours at night by the winding engine, with tubs holding 600 gallons each.

Plate 46 is a drawing of a double-cylindered engine with two double-acting force pumps, as arranged by Messrs. Routledge and Ommaney, of Manchester, for the purpose, when placed underground, of forcing the water to the surface.

This description of engine is becoming more generally used, on account of its simplicity, and its independence of any apparatus except the pumps in the shaft. The circumstances under which it would seem to be applicable would be—

1. When a pit has been sunk by means of the winding engine, and without the necessity of erecting a separate pumping engine at the surface.

2. When, on account of the increase of water in prosecuting the workings, auxiliary pumping power is necessary.

3. Under a reconstruction of pumping machinery.

The principle of forcing water up shafts by this class of machinery can be applied at great depths: it is used by Messrs. Knowles, at their Pendlebury Colliery, near Manchester: in this case the rams are attached to a piston rod passing through each end of the cylinder.

The diameter of the cylinder of this engine (high pressure) is 34 inches; length of stroke 6 feet; and diameter of rams 7 inches.

The column is 300 yards; the lower 100 yards of pumps are 7 inches in diameter inside, with the thickness of the metal $1\frac{1}{2}$ inch, the middle 100 yards, $7\frac{1}{2}$ inches and $1\frac{1}{4}$ inch; and the top 100 yards, $8\frac{1}{4}$ inches and $\frac{7}{8}$ inch respectively.

There is as yet a feeling of insecurity connected with this mode of dealing with the water, on account of the possibility of accident resulting in the drowning of the whole apparatus, but that seems to be gradually wearing away.

Where shafts are sunk for the purpose of working mineral veins, it is customary to sink a vertical shaft for the pumping apparatus, but the drawing shafts are generally sunk in the vein itself, thus certainly having an advantage in the produce of the sinking being valuable, and in saving cross driftings to the veins; but on the other hand, incurring a great sacrifice of wear and tear, and constituting a much less safe arrangement as regards the workmen, who have to descend and ascend by means of ladders, &c., at a large expenditure of time and labour.

The pit, after having been sunk and properly secured, requires to be fitted up with guides or conductors, by which the cages pass up and down the shaft. Many

different modes of arrangement are adopted, but for a pit such as that already described the plan shown in plate 55 will be found convenient in practice. In this case the pit (fig. 1), 14 feet 9 inches in diameter, is divided by a brattice of 3 inch planks into two shafts, one for pumping water and the other for drawing coals.

The buntons to which the guides are bolted are of Memel plank 9 × 3 inches, and 6 feet apart. The guides are $4\frac{1}{2} \times 3$ inches, made of pitch pine. The cage (fig. 3), consists of an upper and lower compartment, to enable four tubs to be drawn at once: the weight of this cage, with its chains, should not exceed 20 cwt. The coal tub (fig. 4) will hold 8 cwt. of coals.

Wire ropes are frequently used as guides: they are usually made of a single strand of thick wires: it is desirable not to have fewer than three guides to each cage, so as to prevent the risk of collision between the cages; and for a shaft of considerable depth the cages should not pass each other nearer than 8 or 9 inches. These guides should be strained quite taut, which may be done either by screws at the top of the frame on the pit top, or by weights hung at the bottom. The latter has, in some respects, the advantage, as it is always in action, whatever variation may take place in the length of the guides from changes in the temperature of the shaft.

During the whole of the time of sinking, the erection of dwelling houses for workmen, shops for joiners and smiths, &c., will have been in course of erection, which, with the necessary skreens, railway branches, and sidings about the pit, &c., having been completed, the colliery is ready for work.

CHAPTER V.

STRENGTH OF MATERIALS—ROPES—PULLEYS--POWER OF ENGINES.

A treatise of this nature would be incomplete without a short chapter upon this subject; but in order to render it of a more specially useful character, it is entirely composed of such rules and modes of calculation as have from time to time been adopted by practical men, in their application to circumstances in which the mining engineer is ordinarily placed.

The late Mr. W. Emerson found that a cylinder whose diameter is d inches will carry permanently as follows:—

Iron	$135d^2$	in cwts.
Good rope	$22d^2$	,,
Oak	$14d^2$	,,
Fir	$9d^2$	,,

A very easy rule for calculating the proof strength of hempen rope is—square the circumference in inches and divide by 10, which will give the number of tons which may be safely appended to the rope. Thus a 10-inch rope will carry 10 tons; a 12-inch rope 14·4 tons, &c. According to Mr. Emerson's formula, a 10-inch rope will carry permanently 11 tons 2 cwt.

To obtain the proof strength of an iron wire rope, square the circumference, and divide by 1·6; and of a steel wire rope, square the circumference, which will in each case give the result in tons: thus an iron wire rope, 4 inches, and a steel wire rope 3·16 inches in circumference, will each carry permanently 10 tons.

The following table shows the comparative absolute strengths of round hempen and wire ropes and chains, with the loads which may in practice be safely appended to them in shafts: the table shows also the weight of each per fathom. The working load is calculated at one-third of the proof strength, in order to insure against any sudden jerks or strains such as are incident to ropes working in shafts:—

HEMPEN ROPES.		IRON WIRE ROPES.		STEEL WIRE ROPES.		CHAINS.		BREAKING STRAIN.	PROOF STRENGTH.	WORKING LOAD.
CIRCUM.	WEIGHT PER FATHOM.	CIRCUM.	WEIGHT PER FATHOM.	CIRCUM.	WEIGHT PER FATHOM.	CIRCUM.	WEIGHT PER FATHOM.			
Inches.	Lbs.	Inches.	Lbs.	Inches.	Lbs.	Inches.	Lbs.	Cwts.	Cwts.	Cwts.
3	2·2	1·2	1·26	·95	·79	...	...	54	18·0	6·0
3½	3·0	1·4	1·71	1·10	1·06	$\frac{5}{16}$	5½	73	24·5	8·1
4	3·8	1·6	2·24	1·26	1·39	...	...	96	32·0	10·6
4½	5·0	1·8	2·83	1·42	1·76	...	...	121	40·5	13·5
5	6·2	2·0	3·50	1·58	2·18	$\frac{7}{16}$	10½	150	50·0	16·6
5½	7·5	2·2	4·23	1·74	2·65	...	...	181	60·5	20·2
6	9·0	2·4	5·04	1·90	3·15	...	...	216	72·0	24·0
6½	10·5	2·6	5·91	2·06	3·71	$\frac{9}{16}$	18	253	84·5	28·2
7	12·1	2·8	6·86	2·22	4·31	...	...	294	98·0	32·6
7½	14·0	3·0	7·87	2·38	4·96	...	...	334	112·5	37·5
8	15·9	3·2	8·96	2·53	5·60	$\frac{11}{16}$	27	384	128·0	42·6
8½	17·9	3·4	10·11	2·68	6·28	...	...	433	144·5	48·6
9	20·1	3·6	11·34	2·84	7·05	...	...	486	162·0	54·0
9½	22·5	3·8	12·63	3·00	7·87	$\frac{13}{16}$	37	541	180·5	60·0
10	25·0	4·0	14·00	3·16	8·74	...	...	600	200·0	66·6
10½	27·4	4·2	15·43	3·32	9·64	$\frac{15}{16}$	49	661	220·5	74·0
11	30·1	4·4	16·94	3·48	10·59	...	...	726	242·0	80·6
11½	32·9	4·6	18·51	3·64	11·59	1	56	793	264·5	88·2
12	35·8	4·8	20·16	3·79	12·56	...	...	864	288·0	96·0
12½	38·9	5·0	21·87	3·95	13·65	...	...	937	312·5	104·2
13	42·0	5·2	23·66	4·11	14·78	1⅛	71	1014	338·0	112·6
13½	45·5	5·4	25·51	4·26	15·88	...	...	1093	364·5	121·5
14	48·8	5·6	27·44	4·42	17·09	...	...	1176	392·0	130·6
14½	52·3	5·8	29·43	4·58	18·35	1¼	87	1261	420·5	140·6
15	56·0	6·0	31·50	4·74	19·65	...	...	1350	450·0	150·0
15½	59·8	6·2	33·63	4·90	21·00	...	...	1441	480·5	160·2
16	63·7	6·4	35·84	5·06	22·40	1⅜	106	1536	512·0	170·6

A sufficiently close approximation to the working load of round wire ropes in shafts is to multiply by 5, the weight of the rope per fathom in pounds, in order to obtain the load in hundredweights; and for steel wire ropes by 8: in the working load is included the weight of rope hanging over the pulley.

As the flat wire rope is manufactured, viz., by laying four or six round ropes side by side, and stitching them with wire, it is evident that it has not the same probability of bearing the strain as uniformly as a round rope of equal weight of material; because should any strand be in the least degree stretched unequally with the rest, the rope is possessed of so little elasticity that the whole of the strain will be thrown either upon it, or upon the remaining strands: the consequence is that, for similar loads, a greater weight per fathom of flat than of round rope is required, probably in the proportion of 5 to 4 at least, exclusive of the weight of stitching.

If the winding engine has been established before round wire ropes were introduced, it is probable that it will be nearer to the pit than is, under the ordinary mode of making the rope coil singly on the drum, consistent (by throwing the rope too far out of lead) either with safety or with the fair use of the rope. The single coil is not, however, by any means a necessity of the round wire rope. I have halved the spread

of a round rope, working on a 14 feet drum, where the depth of the pit was 165 fathoms, and the working load 70 cwt., and the speed very great; and proper care having been taken to make the rope rise over itself when the coil reached the side of the drum, without gripping, I found the ropes to last as long as they did under other circumstances.

The square of the circumference of round hempen rope in inches is equal to the weight in hundredweights of 450 fathoms; or to find the weight of any hempen rope in hundredweights, multiply its length in fathoms by the square of the circumference in inches, and divide by 450.

The square of the circumference of round iron or steel wire rope in inches is equal to the weight in hundredweights of 128 fathoms; or to find the weight of any round wire rope in hundredweights, multiply its length in fathoms by the square of the circumference in inches, and divide by 128.

In calculating the size of ropes it is necessary to take into consideration the speed at which the load is moved, as well as the weight of the load: upon this subject I am indebted to Professor W. J. Macquorn Rankine for the following remarks:—

"During the time when the rope is moving at an uniform speed the strain upon it will be simply equal to the load (including the weight of the rope itself), and will be the same whether the speed is great or small.

"But *at starting and for a few seconds afterwards,* there will be an additional strain depending upon the speed.

"In order to calculate how much that additional strain will be, it is necessary to know how many seconds are to be occupied in getting up the speed from nothing to the full speed.

"Multiply the load by the full speed in feet per second; divide by 32 times the number of seconds occupied in getting up the speed; the quotient will be the additional pull on the rope at starting; which being added to the total weight lifted will give the total pull which the rope should be capable of safely bearing as an ordinary working stress."

This is an important consideration; and is entirely consistent with the fact, that ropes almost always break at or immediately after the lift.

There is a very decided advantage in the application of springs to wire ropes, for their rigidity is such that, without them, not only is there a great strain laid upon the rope at starting, but also a similar strain is experienced by the whole of the machinery attached thereto. The proper place for springs is upon the pulley frames, the carriages of the pulleys resting upon them.

This arrangement, which is due to M. Guibal, of Mons, is adopted at some of the Belgian collieries, and works well: it consists of two strong coach springs with the lower side placed upwards, upon one of which one of the bearings of the pulley rests:

the bearings are kept vertically in their places by strong guides, in which they move up or down, according to the action of the spring.

The diameters of both rope rolls or drums and pulleys should be equal: and if any rule can be given for the apportionment of their size to round wire ropes, the following will be found to work well:—

Assume 10 feet as the minimum diameter of drum and pulley for any rope not exceeding 6 lbs. weight per fathom, and add 6 inches for every additional pound per fathom.

This would give for a 10 lb. rope, a drum			12 feet in diameter.		
12	,,	,,	13	,,	,,
14	,,	,,	14	,,	,,
16	,,	,,	15	,,	,,
18	,,	,,	16	,,	,,

Where the depth of the shaft is very great, so that the weight of the rope becomes of serious importance, conical drums may be used advantageously, each coil laying upon its own bed, formed as a spiral laid upon the tapering surface of the drum. The use of these drums is, however, open to a somewhat serious objection, more particularly as regards the descending cage, as any obstruction to its descent is liable to have the effect of producing a slackening of the rope which may result in its springing off its bed. The bed of each coil should, therefore, clearly not be less deep than the groove of the pulley. Pulleys (plate 55, fig. 2) are constructed with metal naves and rims, the spokes being of iron.

The following formula is applicable in order to determine the weight in pounds avoirdupois which may safely be placed upon the middle of a rectangular beam supported at both ends:—

Let W represent the weight.

a = the length of the beam in inches.

b = the breadth in inches.

c = the depth in inches.

S = the modulus of rupture.

= for English oak	... ...	10·032	(Barlow).
= ,, Canadian oak	... ...	10·596	(do.)
= ,, Pitch pine	... ...	9·792	(do.)
= ,, Red pine	... ...	8·946	(do.)
= ,, Memel plank	... ...	10·386	(do.)
= ,, Larch	... ...	4·992	(do.)
= ,, Cast iron (Alfreton)	... ...	44·046	(Thompson).
= ,, do. (Carron No. 2 cold blast)	...	38·556	(Hodgkinson & Fairbairn).
= ,, do. (do. hot do.)	...	37·503	(do.)
= ,, do. (Elsecar No. 1 cold do.)	...	34·862	(do.)

$$W = \frac{2S \times b \times c}{12a}$$

Thus a beam of red pine 20 feet long, 6 inches broad, and 12 inches deep, would carry with safety 5,367 lbs.

If loaded uniformly along its entire length, the beam will support three times the weight thus calculated.

To calculate the nominal horse-power of a condensing steam engine, square the diameter of the cylinder in inches, and divide by 30; thus a condensing steam engine with a cylinder 55 inches in diameter is 100 horses power.

In this calculation of the power of a condensing engine the pressure on the safety valve is assumed at 3·18 lbs. per square inch, and the effective force on the piston at 7½ lbs. per square inch.

To calculate the nominal power of a high pressure or non-condensing steam engine, square the diameter of the cylinder, and divide by 13·6: thus a high pressure engine with a cylinder of 36·84 inches in diameter is 100 horses power.

In this calculation of the power of a non-condensing engine, the pressure on the safety valve is assumed at 25 lbs. per square inch, and the effective force on the piston at 16·66 lbs. per square inch.

To find the quantity of water in gallons per minute an engine of any given horse power will pump from a given depth:—

Let H = Horse power of engine.
F = Depth in fathoms.
G = Quantity of water in gallons per minute.

$$\text{then } \frac{550\,H}{F} = G.$$

Thus let it be required to find the number of gallons of water per minute an engine of 100 horses power will pump from the depth of 100 fathoms, we have—

$$\frac{550 \times 100}{100} = 550 = \text{the number of gallons required.}$$

To find the number of gallons lifted each stroke by an engine having the diameter of the working barrel or of the plunger, the length of stroke, and the number of strokes made per minute, square the diameter of the working barrel or plunger in inches by the length of stroke, multiply by the number of strokes per minute, and the product by ·034.

Thus an engine pumping 6 strokes per minute with a 6 feet stroke and a working barrel or plunger 20 inches in diameter, will raise

$$20^2 \times 6 \times 6 \times \cdot 034 = 489 \cdot 6 \text{ gallons per minute.}$$

A sufficiently near approximation is obtained by squaring the diameter as above, and dividing by 10 for the gallons of water for every 3 feet of stroke: thus with the data as above—

$$\frac{20^2}{10} \times 2 \times 6 = 480 \text{ gallons per minute.}$$

To find the pressure of water in pounds per square inch, at any depth, multiply the depth of the column in inches by ·03617 (the weight in pounds of a cubic inch of water). Thus the pressure under a column of 100 fathoms is

$$7200 \times \cdot 03617 = 260 \cdot 414 \text{ lbs. per square inch.}$$

With pipes such as are commonly used for water, and with moderate pressure (as distinguished from those to which a hydraulic press is subjected), we have to consider not only the thickness necessary to bear the pressure, but also the least thickness with which it is possible to cast them. Great care is taken to keep the core central, but it is seldom perfectly so, a pipe which is intended to be half-an-inch thick being frequently $\frac{3}{8}$ths of an inch at one side and $\frac{5}{8}$ths of an inch at the other, and of course the least thickness is the measure of the strength of the pipe.

The following formula gives results which in practice, and with good metal, may be adopted with safety :—

Let x = the required thickness in inches.
D = the diameter of the pipe in inches.
P = the pressure or vertical depth in feet.

$$\text{Then } x = \left(\frac{\sqrt{D}}{10} + \cdot 36\right) + \left(\frac{D \times P}{25000}\right)$$

Thus the thickness of a 20-inch pump at 60 fathoms would be—

$$\left(\frac{\sqrt{20}}{10} + \cdot 36\right) + \left(\frac{20 \times 360}{25000}\right) = 1\cdot 095 \text{ inches; and for 100 fathoms, } 1\cdot 287 \text{ inches.}$$

The subjoined table has been constructed for the purpose of showing the power of winding engines required for raising loads from mines. To the calculated power is added 50 per cent., this increase being considered necessary to overcome the friction of the conductors in cage shafts, and also to give the engine sufficient command of its work, as in overcoming inertia at the lift: it is presumed that the weight of the rope is so balanced as to require no exercise of engine power to set it in motion.

Assuming the quantity required to be 600 tons drawn daily, the load, speed in shaft, and power of engine may be adjusted to the depth, as follows :—

DEPTH.	LOAD.	SPEED.	TIME OF DRAWING AND CHANGING.	POWER OF ENGINES.		
				1	2	3
FATHOMS.	CWTS.	FEET PER SECOND.	SECONDS.	CALCULATED.	ALLOWED FOR FRICTION, &c.	TOTAL.
50	2 tubs = 16	10	40	33	17	50
75	2 tubs = 16	14	40	45	22	67
100	2 tubs = 16	18	40	58	29	87
125	3 tubs = 24	15	70	74	37	111
150	3 tubs = 24	18	70	88	44	132
175	3 tubs = 24	21	70	102	51	153
200	3 tubs = 24	24	70	117	58	175
225	3 tubs = 24	27	70	132	66	198
250	3 tubs = 24	30	70	146	73	219
275	4 tubs = 32	24	90	157	78	235
300	4 tubs = 32	26	90	169	84	253
325	4 tubs = 32	28	90	182	91	273
350	4 tubs = 32	30	90	196	98	294
375	4 tubs = 32	32	90	208	104	312
400	4 tubs = 32	34	90	220	110	330

The above powers are sufficient to draw 600 tons of coal in a day of 10 hours, should it be desired to do so.

The diameter of cylinder of the above engines may be ascertained by the application of the formula for the nominal power of engines to the figures in column 1: thus a condensing engine for the depth of 250 fathoms should have a cylinder 66 inches in diameter, and a double-cylindered high pressure engine for the depth of 300 fathoms should have each cylinder of the diameter of 34 inches. Engines of such nominal horse power when at their work and in speed would probably indicate as high as the horse power in column 3.

CHAPTER VI.

THE WORKING OF MINES.

ROCK SALT—IRONSTONE—COAL—LONG-WORK—BOARD AND PILLAR WORKING—UNDERGROUND HAULAGE—WORKING COAL BY MACHINERY—COPPER, LEAD, AND TIN.

THE varied circumstances under which different minerals exist would appear to lead easily and naturally to much dissimilarity in the methods pursued in their extraction: as has been already explained, some minerals are found in horizontal layers or strata of extraordinary thickness, such as rock salt: some, on the contrary, are discovered in thin bands, such as most of the ironstone beds of the coal measures: some, such as the ordinary workable seams of coal, exist in the form of strata of moderate thickness: and some are found in fissures or veins, such as those minerals or ores from which the greater part of the metals (excepting iron) are procured.

Still, the chief principles involved in the extraction of the whole are similar: the sinking of the shafts, the drainage of the water, the raising of the mineral, and the ventilation of the mines, all require their modicum of care; and we find that, notwithstanding the apparently opposite requirements of such widely contrasted elements, the mode of management of the whole is possessed of one (very nearly) general character, with variations only in detail.

1. ROCK SALT.

The general principle upon which rock salt is mined, is to obtain as much salt as is consistent with the maintenance of the superincumbent strata: pillars of salt being left for this purpose.

The rock salt pits (says Williams, Mineral Kingdom, vol. 2, p. 205) are immense excavations, some of which are not less than 320 feet in diameter; and in digging out the salt, massy pillars are formed out of the rock for the purpose of supporting the roof, which is of the same material, a thickness of about 20 feet of the salt being left for the purpose.

Among the most interesting accounts of the English salt mines is that of Sir George Head, contained in his Tour through the manufacturing districts of England,

in 1835. Whilst at Northwich, he visited the Marston pit, which had been at work for a period of sixty years, and may be considered inexhaustible.

Having waited, says he, with my conductor for a few minutes till the engineer had put a little steam on, we stepped into a round tub, and standing upright, holding by the chains, were let down very easily. I cannot express the delight I felt at the scene around me, which surpassed anything I had anticipated; creating those sensations I remember to have felt when first I read of the pyramids and catacombs of Egypt. Here was a magnificent chamber, apparently of unlimited extent, whose flat roof presented an area so great, that one could not help being astonished at its not having long since given way; yet there was no apparent want of security, it being sound and durable as if formed of adamant. Here and there, pillars in size like a clamp of bricks in a brickfield, tendered their support, presenting to the view an array of objects that broke the vacancy of uniform space. My idea of the extent was, as if an area equal to the site of Grosvenor Square were under cover. In the meantime, the glistening particles of crystal salt on the walls, and the extreme regularity of the concentric curved lines traced by the tools of the workmen, were very remarkable. Occasionally, the mark of the jumper chisel was observable, where recourse had been had to blasting the solid rock. I made a few blows against the side of the mine, with one of the heavy pointed pickaxes in ordinary use, and found it as hard as freestone.

Under foot, the whole surface was a mass of rock salt, covered with a thick layer of the material, crushed and crumbled to a state that exactly resembled the powdered ice on a pond, that has been cut up by skaters.

At one part there is a vista, of 200 yards in length, which has been dignified with the name of Regent Street.

The salt, after being prepared by the solution of the rock and evaporation, is formed by wooden moulds, with holes in the bottom to allow the remaining water to pass through, into cubical blocks, and in this state shipped.

A considerable quantity is prepared from the brine springs, some of which are so strongly saturated as to hold in solution the greatest possible quantity of salt. To the water of others, rock salt is added while boiling in the pans. From these springs the water or brine is raised from a shaft by a pump worked by an ordinary steam engine. There does not appear to be anything worthy of especial remark in the mode of raising salt, the whole process appearing to consist in a system of wide excavations, leaving such pillars or barriers as are sufficient for the support of the roof.

2. IRONSTONE.

Ironstone usually being either stratified or existing in the form of nodules in strata of shale, may be worked either by what is termed the "long wall" method, as practised in Staffordshire and elsewhere, or by the "board and pillar" method," as adopted in the Newcastle coal field.

1. The Long Wall.—The great distinguishing feature of this mode of extraction consists in removing the whole stratum out of the mine, as our operations advance. In order to effect this, we proceed as follows:—Supposing we have two shafts sunk to the ironstone bed, the first operation is to form a communication between the two, for the purpose of ventilating the mine. After this has been done, certain excavations require to be made which are intended to serve as passages for bringing the ironstone to the drawing shaft, for conveying a current of air into the workings, and also for allowing the return of the air which has ventilated the working places to the upcast shaft. The manner of laying out such workings will be seen on referring to plate 56, figure 1.

Let A be the downcast shaft, used also for drawing the produce of the mine, and B the upcast.

In the first instance, then, we connect A with B, and then commence driving the drifts A*b*, A*c*, &c., which have the effect of placing pillars of stone round the shafts, which act as barriers for their preservation against any injury which they otherwise might sustain from the extraction of the ironstone. After having completed these barriers, we turn our attention to the winning out of a face of work, which we do as follows:—From the points *b* and *c*, we drive in a waterlevel direction the drifts *b e*, *c f*, accompanied by consort drifts *g h*, *i k*, forming communications between each pair as it advances, at stated distances—suppose 40 yards—taking care as every new holing is made, to close up with a strong stopping of brick or stone the previous one. This (proper means having been applied at the bottom or top of the upcast shaft) will cause the necessary circulation of air. After these have been continued a certain distance—say 150 yards—in each direction, and at the same time other excavations (*l m*, *n o*, &c.), having been completed, the working of the mine may be prosecuted upon the wall faces *l m*, *n o*, and the ironstone conveyed to the shaft by a railway or tramway, laid as represented by the blue shade.

The red lines and arrows represent the air stoppings and circulation of the air.

The wall face being divided into suitable "stints," a certain description of workmen called "holers" is distributed along the face of the work. The business of these men is to undermine the ironstone to the extent of, say, 30 inches: these men are followed by another set called "builders-up:" they are provided with a sort of pick called a dresser, having only one sharp end, the other being short and forming a hammer: their duty is to get down the ironstone which has been undermined by the holers, and to build up behind them the stone which falls with the ironstone. Sometimes the holers both undermine and get down the ironstone, and build up the refuse themselves, and then their stint is arranged accordingly. At the same time that the refuse is thus built up to support the roof, and stout wooden or metal props placed under dangerous places, the "loaders" and "pitchers" are at work. Their duty is to load the skips or tubs, and also to take up the rails and lay them down again, as the work advances.

It is necessary to leave gateways through the waste or excavated part as the work proceeds, these gateways being pillared at the sides partly with stone taken from the roof of the gateways, which are thus made of extra height, in order to prevent their being so reduced by the thrust as to render them useless. As the wall face advances still further (plate 56, fig. 2), and the gateways become in consequence inconveniently long, a cross heading is prepared ($x\ y$), along which the ironstone is conveyed after being brought thereto by the gateways.

We must not omit describing an important part of the economy of every mine, as without a due attention to it the workings are always liable, especially when burdened with much water, to be suspended: I allude to the standage, or lodge, which is a reservoir for the mine feeders, the lowest point of which is on a level with the bottom of the engine sump. The standage consists of a portion of workings excavated on the dip side of the shaft, with the bottom of which it is connected by a water-level drift, in which is placed a dam with a pipe in it, through which, under ordinary circumstances, the water flows to the engine.

When from any cause, however, the pumping is stopped, the pipe is plugged up, and the water allowed to accumulate in the standage, until pumping can be recommenced, when the plug is withdrawn.

2. Board and Pillar, called also Post and Stall Work.—In this instance the preparatory workings, so far as the holing about of the shaft pillars and the driving of the water-levels are concerned, are similar to those above described. In place, however, of carrying the whole of the face work forward together, boards, or excavations 4 or 5 yards wide are turned away at distances of 2 yards or upwards apart, and driven as far as is considered convenient, the rubbish being stowed away or pillared up by the side of the board as it advances; or in case of there not being sufficient stowage for it, it is sent to the surface and teemed into the refuse heap.

After these boards have been driven as far as is thought proper, they are communicated with each other by means of narrow holings called walls, which have the effect of leaving a portion of the mine in the form of pillars, which may afterwards be worked away. Plate 56, figure 3, shows the arrangement of workings upon this plan, the blue lines showing the position of the tramways, and the red lines and arrows the stoppings and direction of the currents of air.

In some places beds of ironstone lie so near the surface that they are worked as quarries: instances of this occur at Westbury, and Seend, in Wiltshire; as well as in Northamptonshire, Lincolnshire, &c.

3. COAL.

The first authentic record which we have of coal being worked in the vicinity of Newcastle-upon-Tyne, is that King Henry III., by his letters patent under the great seal of England, dated at Westminster the 1st day of December, 1239, in the twenty-

third year of his reign, upon the good men of Newcastle's supplication, thought it fit to give them license to dig coals and stones in the common soil of this town, without the walls thereof, in the place called the Frith, and from thence to draw and convert them to their own profit, in aid of their fee farm rent of £100 per annum, and the same as often as it shall seem good unto them: the same to endure during his pleasure; which said letters patent were granted upon payment of twenty shillings into the hamper.

Edington, in his Treatise on the Coal Trade (1813), states regarding the working of these mines, "it may be seen to this day where their watercourse comes out to the surface at Gallowgate, from near the bottom of the Moor: the High main run out, the only coals they wrought were the Metal coals, which lie about 5 fathoms below the High main, the seam about 32 inches thick, pretty good, and about 4½ fathoms below lay the Stone coal, about 30 inches, pretty good."

Not many years afterwards, we find that coal was wrought in Scotland, in lands belonging to the Abbey of Dunfermline, viz., in the year 1291, a charter granting the right of digging coals in the lands of Pittencrief having been granted in favour of the Abbot and convent.

It is probable, however, that coal was wrought long previous to the above dates, and the author of Britannia Romana tells us that a colliery was established not far from Benwell (the Condercum of the Romans) during the period in which that people lived in Britain.

Notwithstanding the early date at which the working of coal commenced, and the enormous extent to which it is now carried, the following extract from a memorial to the Crown by Sir Kenelm Digby, in 1661, shows that a coal fire was not always so popular as at present:—

"This coal flies abroad, fouling the clothes that are exposed a-drying on the hedges, and in the spring time besoots all the leaves, so that there is nothing free from its contamination; and it is for this that the bleachers about Haarlem prohibit, by an express law (as I am told), the use of coals for some miles about town. Being thus incorporated with the very air which ministers to the necessary respiration of our lungs, the inhabitants of London, and such as frequent it, find it in all their expectorations, the spittle and other excrements which proceed from them being for the most part of a blackish and fuliginous colour; besides, the acrimonious soot produces another sad effect, by rendering the people obnoxious to inflammations, and comes in time to exulcerate the lungs, when a mischief is produced so incurable that it carries away multitudes by languishing and deep consumptions, as the bills of mortality do quickly inform, &c., &c."

In working coal, as in the case of other minerals, the object has been, and is, to obtain as much coal as possible from a given area, and the greater or less proportion of coal obtained would naturally at first depend altogether upon the nature of the

roof: thus a very bad roof would not only necessitate the excavations to be driven of a less width, but also the pillars to be left of a greater strength than would be required by a roof of a firm description. The quantity obtained in the earlier stages of mining was also dependent upon the depth, for as this increased, the additional weight of superincumbent strata demanded that the pillars should be left of greater size. The dimensions of the pillars found in old workings at Butterknowle, near the south-west outcrop of the lowest seam of the Newcastle coalfield, where the depth is not more than 7 or 8 fathoms, are about three yards square; the width of the excavations being about three yards, and the whole driven beneath 8 or 10 inches of top coal, and accurately arched, the object of the arching being to prevent the use of props. At the date of these workings (probably 200 years ago), the whole of the extraction was performed by horses and gins, the pumping of water being performed by the same means. The pits were of moderate depth, and 20 or 30 tons were esteemed a great day's work from a single pit. The great difficulty that seems to have been met with in the prosecution of these old mines, appears to have been the working of coal to the dip of the shaft levels; and although we occasionally find that when the waters have been light, the workings have been extended to the dip by means of rag wheel pumps, yet these instances are not of frequent occurrence, and seem generally to have been attended by the precipitate abandonment of the colliery, the tools of the workmen having been left behind.

From such working apparatus as has been discovered, it appears that the coal has been conveyed in barrows from the hewer to the shaft, whence the origin of the present terms barrow-way and barrow-man. Iron picks were in use of much the same form as those at present employed; the shovels were made of wood, and the application of gunpowder to the working of coal was at this time unknown. Some of the work performed by these old miners surprises us by its beauty, and by the patient toil with which it has been executed. We have in various places, among which may be mentioned Tanfield Moor and Beamish, instances of very long water-courses, driven sometimes in stone and sometimes in coal, the width of which does not exceed 18 inches; and it is truly a wonder how the work has been performed, the sides of the drifts being as smooth and straight as though they had been chiselled. There are also instances of very deep levels finished with the same precision: one of these I remember to have seen in the old workings at Tyne Main, the depth of which was 16 feet, and the width at the top not more than 3 feet.

As the coal became exhausted at moderate depths, and it became necessary to obtain the supply from deeper winnings, the means in use were found inadequate to the purpose, but as has ever been, and ever will be the case, the prospect of gain so stimulated man's ingenuity as to enable him to meet the emergency.

Pits were sunk near to running streams, and their waters made to perform the work no longer practicable by old means; and eventually the steam engine was applied

to mining, great improvements since its introduction being suggested at different times by the various circumstances occurring in practice.

Coals were formerly all drawn to the surface in corves containing about 10 pecks, but as the power of the machinery increased, the dimensions of the corf were also enlarged, and at the introduction of the tub and cage system, the size of the corves was usually from 20 to 30 pecks, two or three being drawn at a time. The system of drawing coals in cages was introduced into the Newcastle district by the late Mr. Thomas Young Hall, about the year 1832, the first pit fitted up on this principle being the Glebe pit at Towneley Colliery, near to Ryton. Notwithstanding that at first the plan was not very highly thought of, it has long completely superseded that of drawing coals in corves, now quite, except under particular circumstances, exploded. The saving effected in the North of England by this introduction may, on a rough estimate, be taken at £100,000 (4,000,000 scores of 6-tons at 6d. per score) per annum, as the difference between the annual cost of the corves and tubs alone, to say nothing of other mining improvements consequent upon the change.

Upon this subject it is, however, just to the memory of the late John Curr, of Sheffield, to make the following extract from his work entitled "The Coal Viewer and Engine Builder's Practical Companion," which was published in 1797, page 36 :—

"—— being myself the patentee for the invention of the conductors to prevent damage to the corves and shafts, I will only recommend it to the interested public, to take a view of the methods now established at sundry collieries near Sheffield, Barnsley, and Leeds, and let them judge for themselves. These conductors are nothing more than two or three *upright rods* of deal 4 × 3 inches, braged upon opposite sides of the pit, forming mortises or channels, by which the corves are conducted, being suspended upon cross-bars with rollers at their ends which run within the mortises."

As regards the most economical method of working coal, some difference of opinion exists : the board and pillar, and long-wall method, each possessing its advocates : the general principles of these two systems have been already explained, when treating of the working of ironstone ; their application to the working of coal is, however, of sufficient importance to demand a little further explanation.

The system almost exclusively adopted in the Newcastle coalfield, and also, with certain modifications, made use of pretty generally in Scotland, Lancashire, and elsewhere, is that termed the board and pillar, or post and stall, method of working coals. (Plates 56-60.)

The situation of coal pits varies so much, together with the position of the seams of coal, dikes, and slips, that no rule can be laid down for the form of the pillars of coal left near the shaft, which are called the shaft pillars.

Suffice it to say that the drift intended for the main outlet or rolley-way from the colliery workings to the shaft should be driven with about 5-16ths of an inch

rise per yard each way from the shaft, and as straight as possible, in order that it may be adapted to the application of machinery as the tractive power to be used upon it.

The shaft walls should seldom be less than 40 yards square, and should increase in proportion to the depth or tenderness of the coal to be worked. If we suppose the minimum to be 40 yards, and 5 yards to be added for every additional 10 fathoms of depth above 80, we should have for a depth of

100 fathoms	50 yards.	
150 „	75 „	
200 „	100 „	&c., &c.

Pillars of this large size may be subdivided, and it would be neither safe nor expedient to form them by one-holing. During the holing of the shaft walls, a fire-lamp placed at the bottom of the upcast will cause an excellent current of air to traverse the places as they proceed: the diameter of such a lamp may be 3 feet. If, however, the nature of the seam of coal is to produce much inflammable gas, the ventilation (in the absence of the permanent ventilating apparatus) may be performed by a steam jet apparatus, and the whole of the preparatory workings should be effected under the employment of safety lamps. After the shaft walls have been holed, the permanent ventilation of the colliery ought to be established as soon as practicable.

The rolleyway drifts must now be continued in each direction from the pit, and two other drifts should be set away, parallel to them, out of the shaft walls, one on the rise and one on the dip side of the rolleyway drifts.

To prevent confusion, it may be as well to state that as the workings at each side of the shaft will probably correspond with each other, we shall follow those which proceed to the north, supposing the water-level line to be north and south, and the full rise to be west at the rate of 1 in 24, or 1½ inches to the yard. I shall also assume that the coal pit is 150 fathoms in depth, 15 feet in diameter, divided by a plank brattice 3 inches thick into an engine or pump shaft, and a coal shaft; that the direction of the brattice is north and south; that the upcast shaft is also 150 fathoms in depth, 10 feet in diameter, and situated 75 yards west of the coal pit. According to the rule for the size of the shaft pillars, they will be each 75 yards square.

We have, then, three drifts—viz., the rolleyway, the high water-level, and the low water-level drift, proceeding parallel to each other, in a northern direction; and as these are the main drifts of the mine, they must be driven with great care, and about 7 feet wide. (Plate 57, figure 1.)

The thickness of the pillars of coal left between the high water-level and the rolleyway, and also between the rolleyway and low water-level, may in this case be 25 yards, but of course for a less depth, other things being the same, a less thickness will be sufficient.

It will be commonly found that the thickness of the pillars of coal to be left will depend much more upon the nature of the thill stone or floor of the coal than upon any other circumstance; for when the thill is soft, it is very liable to heave or swell up, especially when wet, when the pillars of coal are not sufficiently strong for the support of the superincumbent pressure.

These drifts will require to be holed across for air every 30 or 35 yards, but the longer these pillars can be made, the stronger and better they will be.

At the holing of every new pillar, a stopping of brick or stone (behind which, for its support, as well under ordinary circumstances as under the contingency of an explosion, 6 or 8 yards of solid stowing should be placed), or, if required, a pair of trap doors should be inserted in the last holing, or stenting wall as it is termed in the north of England, to cause the current of air to pass the face of the drifts. (Plate 57, figures 1 and 2.)

The doors, F. D, should not be air-tight, to allow a portion of air to pass along the centre drift: the arrows represent the course of the current of air. Figure 2 shows the mode of conducting the air into the face by brattices, which, if the seam generates much fire-damp, must be carefully put in, and, when made of deals, if necessary, plastered at the joinings of the deals with hair and lime. Canvas, made air-tight with a preparation of tar, is now much used instead of deal brattices.

Since the main drifts are driven in a water-level direction, they may happen to be either headways, boardways, or cross cut, according to the direction of the strata as compared with the course of the cleavage of the coal. Should they happen to be headways, the boards may be turned away out of the higher drift, as shown in plate 57, figure 3, the first pillar being of larger dimensions, in order to act as a barrier to preserve the main drifts from any thrusts or creeps occasioned by the working away of the pillars beyond; such thrusts or creeps not only being the cause of much expense in keeping these main drifts open, but also prejudicial to the ventilation, by the injury they occasion to the stoppings required to carry the air round the workings.

If the course of the water-levels should be boardways, a pair of winning headways should be set away to the west, at a sufficient distance from the shaft to allow of a good shaft siding between the shaft and the point where the headways are set away, say 100 yards. These headways should contain between them the same thickness of coal as that left between the water-levels, or 25 yards; and out of the back headways the boards may be turned narrow out of the winning headways or water-level drifts, thus often preventing an expense consequent upon the fall of the roof in wide excavations.

Should the inclination of the seam be trifling, the same process may be carried on to the dip or east side of the main drifts, and thus more pit-room obtained.

It will be sufficient for our present purpose to suppose that the course of the water-level drifts coincides with the cleat of the coal, as represented in plate 57, fig. 3.

Since we have assumed the coal to lie at the depth of 150 fathoms from the surface, we shall probably find it convenient to drive the boards five yards wide, with 20 yard walls intervening, forming 25 yard winnings: the walls may be holed at 24 yards, 2 yards wide.

At a proper distance north of the shaft, which in the present case may be 200 yards, the west workings must be formed in the manner shewn in plate 58; the centre drift being the future outlet for that portion of west coal intended to form a district, the width of which may be 400 yards or thereabouts.

After the west workings have advanced a few pillars, they will present the appearance shewn, and then, under favourable circumstances, the working of the pillars may be commenced in the situation marked A.

The circumstances which will regulate the working of the pillars are as follows:—

1. The nature of the mine as regards the production of inflammable gas; because if this be produced in large quantity, the utmost care and judgment will be called into requisition to prevent the possibility of its forming such a compound with the air current as would ignite at a ventilating surface.

In a very fiery mine, the pillars ought not to be worked away before having reached a considerable distance from the shafts, but the first excavations should be preserved as air-ways, through which the return air may be coursed or "dashed," so as to be thoroughly mixed below the firing point, before its passage over the furnace. Risks of this kind are removed by the use of a separate channel for the goaf air into the upcast, or by the use of any mechanical ventilation, or by steam ventilation.

2. The nature of the coal: if the coal be of a tender description, but required to be wrought as large as possible, the working of pillars should be delayed, and their strength made considerable; because if they be worked away, the probability is that those left for the support of the waggonways will be completely destroyed by the pressure: this assumes the roof to be good. In the case of a bad roof, the pillars should be worked away behind the whole, not only from economy in the first instance, but also because, when the roof is bad and falls freely in the goaves, it soon sustains the superincumbent pressure, and relieves the pillars next to the rolleyways.

The advantages of following up the pillars behind the whole, consist in the concentration of the working districts, and the greater facility of keeping a limited extent of workings well ventilated than an extent spread over a wide area.

Various plans are adopted in removing pillars, and no rule can be laid down for the selection of any in preference to others, as what may suit the circumstances of one situation, may in other cases be quite inapplicable.

1. The pillars may be taken off in lifts from each headways course, a place being driven next to the goaf, half the length of the pillar, and about six yards in width.

This plan, except under a very good roof, is objectionable, on account of the quantity of props that it usually requires, the time occupied in removing each lift being considerable.

Another plan consists in laying the tramway down the old board adjoining, and driving over a narrow wall in the pillar, and then bringing the lifts back towards the headways course.

This plan can only be adopted when the stone in the board has not fallen, and although it is attended with (as regards the last lift) less waste of timber (the props being taken out and the roof allowed to fall as the coal is worked back), still there is a considerable quantity used; and, moreover, there is the additional expense of driving so much narrow work, to say nothing of the inferior size of the coal such work produces.

3. Another plan is to split the pillar, as it is termed, by driving a narrow place or jenking down the middle of it to the next headways course, and to bring simultaneously the portions of coal left at each side, between the jenkings and the boards. By this plan there is a considerable saving in timber; but as it has the effect of weakening the support of the strata above, it is often attended by a lifting up or partial creeping of the thill, which is troublesome and expensive.

4. Another way is to drive a narrow place alongside of the board when it is fallen, or to make use of the board itself when it is not, and bring back the whole of the pillar at once: this plan is preferable to the last, as regards liability to produce creep, but it consumes more timber; and the fact implied by an increased consumption of timber under such circumstances is, that the coals are produced in a less marketable state, and that the working places are less safe.

5. The best method, however, consists in making, in the first instance, the pillars of such dimensions as to allow, after driving a jenking up the middle, the portions between the jenkings and boards to be of a fair proportionate size to the depth of the mine: by this plan, no ill effects as regards creep can possibly be produced. After the jenking has reached the far end of the pillar, the whole of the wings on each side may be brought back simultaneously, chocks or metal props being used in double rows, for the support of the roof, the back row, or that next to the goaf, being shifted between the front row and the coal as the face advances.

The chocks consist of hard wood, and should be about 2 feet long, 8 inches broad, and 6 inches thick: they are built up, two upon two, crosswise, the bottom two being placed upon 18 inches of small rubbish, which, being picked out, occasions the easy removal of the chocks when so desired.

The pillars of chocks will be placed at distances apart according to the nature of the roof: under an ordinary roof, they may be placed 9 feet apart, centre and centre; and when the back row is moved forward, it is necessary to use a few strong props to secure the person employed in its removal.

If, instead of chocks, metal props are used, they may either be set upon the thill, in which case, if any heaving takes place, they require to be drawn by the aid of a powerful lever, or they may be set upon a chock placed upon small rubbish, and drawn as above described. These metal props weigh about half a hundredweight to the four feet length, and will support, without breaking, 60 tons each, if properly formed. The best section is that shown in the diagram.

In every colliery, whether it be determined to follow up the pillar working close behind the whole, or to bring the pillars back, it ought to be a peremptory rule to regularly work such a proportion of pillars as will not allow of their accumulation. In the case of following up, this is easily managed; and in that of bringing back, it is only necessary at stated distances to forewin the pannels, the previous one being in the course of pillar working, when that before it is progressing in the whole mine.

As regards the ventilation of workings when the pillars are not removed, this must be effected by "coursing" the air; or, after it has been carried along the face of the boards, traversing it up and down the back pillars, until it reaches the main return air-courses.

The plan of coursing the air was contrived by Mr. James Spedding, of Workington, in 1760, according to Mr. Buddle, one of the most able pitmen of his day.

Air is usually coursed "two and two," or "three and three," according to the greater or less quantity of fire-damp evolved; the meaning being that the current in the former case is conducted up two boards and down two, by means of stoppings of stone, called sheth stoppings, placed in every second wall in each headways course; every alternate line of walls in which the stoppings are placed being open at the top, and the others being open at the bottom, of the sheth of boards, so as to afford the air a free passage. The going headways at the face is frequently made a part of the course, doors, called sheth doors, being substituted for the stoppings, but it is far better, as mentioned above, to conduct the air singly along the face headways course, by means of board end stoppings, and course the air behind them. When the pillars are worked away behind the whole, there are comparatively no old workings to course, and consequently the expense of building so many stoppings, and keeping so large an extent of air-course in a proper state of repair, is saved.

In the ventilation of fire-damp mines conducted on the following-up system, the great point to be attended to is the regulation of the pressures of the air currents in such a manner that, in case of any leakage of stoppings next to the face, the air may pass from the whole into the pillar workings; and the greatest care should be taken that the contrary should on no consideration be allowed to take place.

A reference to plate 59 will show how easily a grave error may be inadvertently committed. In both cases the currents of air may be quite sufficient for all ordinary, and even some extraordinary circumstances; but let us suppose that the stoppings

"*a*" in figure 1, and "*á*" in figure 2 are injured, and that a sudden discharge of gas from the goaf takes place, and enquire what will be the consequence in each case.

In figure 1, the distance from the point "*x*," where the air is divided, to the point "*a*," whether measured along the back pillars, or along the face headways course, being equal, the pressure on the stopping "*a*" might be supposed to be indifferent either to or from the whole workings; however, when we consider the effect of the regulator, the probable contraction of the face air by the brattices of the boards, and the resistance offered to it by the motion of the tubs, we shall conclude correctly that the pressure will in this case be out of the broken into the whole.

In figure 2, however, with precisely the same distribution of air into whole and pillar workings, we see that no possible contingency could occasion the passage of the pillar air into the whole headways course at the point "*á*." This is a most important matter; and I do not know any part of his profession in which the skill and forethought of the colliery viewer is put to a more severe test, than in this; particularly when workings become extended, and the air is many times divided and subdivided.

The Long-wall method of working coal practised in the Midland counties so closely resembles the Long-wall method of working ironstone, already described and illustrated in plate 56, that any further mention of it is unnecessary.

The following calculation shows an approximation to the probable saving by working the longway, so far as the per centage of round coals from a given area is concerned:—

1. By Board and Pillar Work.—Suppose the extent of the property to be 1,000 acres, and the barrier to be 22 yards, then the proportion left underground in barrier, and of course irrecoverable, is	4·00 per cent.
Suppose the winnings to be 12 yards, and to be holed at 26 yards, 2 yards wide; also that in working the pillars, 1 yard in width for the whole length of the pillar is lost (and this is a very moderate computation), this amounts to	8·33 per cent.
The coal which is rendered unavailable by troubles, &c., cannot be taken at less than	2·66 per cent.
Coal lost underground	15·00 per cent.
If the mine is wrought by separation, viz., the workmen separating the round from the small coal, and only sending the former to the surface, the proportion of small left underground and skreened out at bank will be at least on the average equal to 30·00 per cent.; and if the coal is filled up altogether, 33·00 per cent.: and supposing, in three-fourths of the mines, the whole to be sent to the surface, the average quantity of small coal taken out may be 32·25 per cent., or of the whole area,	27·41 per cent.
Total loss by barriers, pillar working, and skreening,	42·41 per cent.

2. By Long Work.—By the long wall, the loss by barriers and troubles will be the same as in the former estimate, viz. ...	6·66 per cent.
There will be a considerable proportion of round coal in the kirvings, but since when the juds fall some small will be made, we may take the whole of the kirvings to be small coal. On the supposition that the thickness of the seam is 4½ feet, and the average height of the kirving (or undermining) 8 inches, the produce of the small from the coal worked will be 14·8 per cent., and of the whole area	13·81 per cent.
Add additional loss in transit from workings, over skreens, and into waggons	8·00 per cent.
Total loss by barriers, working, and skreening ...	28·47 per cent.

According to the above estimate, the produce of round coal from 1,000 acres worked by the board and pillar method, as compared with the same extent worked by the longway, would be in the proportion of about 58 to 71.

The circumstances under which the long-wall system is most applicable are as follow :—

The seam should not be fiery; or, if fiery, should be worked exclusively with safety lamps.

Thin seams are most economically worked by long-wall.

The roof should be of such a nature as to be taken down, in forming the gate roads, without much difficulty, and should consist of tolerably hard stone.

A seam of coal containing a band of stone is well adapted for working by the long way.

The depth from the surface is immaterial.

There are several intermediate methods of working coal, partaking of both principles explained above; for instance, in several of the northern collieries, the plan of leaving very large pillars—say 50 yards square—with the intention of working off such pillars by long work, has been adopted, and with considerable success, both as regards the produce of round coal and the cost of propping; and also in many of the Midland collieries, and more particularly in Lancashire and Cheshire, as illustrated in plate 60, instead of carrying the face forward and following it by roads through the goaf, or protected by pillars, the plan of at once driving excavations to the extremity of a district, and bringing the wall-face either abreast or in slices backwards towards the shaft, is most approved of.

The method of working the Thick or Ten-yard seam of South Staffordshire varies from any of those mentioned.

A section of the Ten-yard Coal is as follows :—

	FT.	IN.
White coal	3	0
Tow (or tough coal)	2	3
Carried forward	5	3

	FT.	IN.
Brought forward	5	3
Benches and Brazils	4	6
Foot coal	2	3
Slip bat	2	3
Slips	2	3
Stone coal parting...	0	4
Stone coal and patchells	4	6
Penny coal	0	6
Springs and slippers	4	6
Humfry batt	0	4
Humfries	2	3
	28	11

The manner of working this seam consists in driving a pair of drifts from the shaft, and after these have reached as far as the winning is required to extend, other excavations are turned away out of them, narrow, and after proceeding a few yards, are laid out wide in a manner not unlike that adopted in the rock salt mines, small pillars 7 or 8 yards square being left at stated intervals for the support of the roof.

The first process of extraction consists in undermining the bottom part of the seam with light picks, building up small supports of stone called "cogs" to support the mass of coal. A sufficient quantity of coal having been thus undermined, the next operation, done by the same men, is to cut upwards between the mass of coal which is intended to fall and that which is intended to stand, as a pillar to support the roof of the mine. This cutting or separating the coal from the pillars must be performed on both sides of the mass which is to be let fall, and also at the end, where it joins on to the remaining solid mass. It would not be safe, however, to cut it in this way completely off from the pillars, so that small supports or webs are still left, called "spurns," which connect the mass to be thrown down with the pillars. The coal is cut through until the parting is reached which forms a natural division of the lower bed from the next above it, or sometimes two beds are cut through at once, but always to a natural parting, the cutting being made perpendicularly up the face of the pillar. After the cutting up is completed, and the men have withdrawn, the most skilful with a long pricker cuts and tears away the spurns and cogs, when the mass of several tons falls together. In this manner, after holing out the lower beds, those above are successively brought down.

Where, instead of having a seam of coal of the enormous thickness thus described, we have the thickness of the bed not more than from 12 inches to 2 feet, as in Somersetshire, the board and pillar system, from its expense, is generally inapplicable: the usual way of working is either to make height for a roadway, and work from it on each side as far as convenient, or to work the coal by the long way, stowing as much rubbish as possible, and drawing the remainder to the surface.

The various alterations and improvements which have taken place in the mode of conveyance of coal underground, from the face of work to the shaft, have contributed so materially to increase the quantities produced at individual mines, that a brief sketch of them may not be inappropriate in this place.

The first method adopted was that which did not require any particular sort of carriage or description of road: a simple basket, filled with coal, and carried upon the back from the face to the shaft, and in some instances to the surface, constituting the whole apparatus. This rude system (the coal being carried by women) was prevalent in parts of Scotland until it was suppressed by an Act of Parliament, 5 and 6 Victoria, cap. 99.

The next means used appears to have been the wheelbarrow, which we discover by the old materials found in recently opened ancient workings to have been in general use about the seventeenth century.

Next came the sledge, or sled as it is commonly called, which consisted of a wooden box resting upon iron shoes, and drawn along the pavement of the coal. These were probably in common use one hundred years ago, and are still in existence in some of the collieries of the south of England.

The next improvement was the substitution of planks for the floor of the coal for the sledge to slide upon.

The attaching of wheels to the sledge soon suggested itself, thus constituting very nearly the tub now used; but it was many years before the tub so nearly stumbled upon was applied as at present. Shortly, however, after the contrivance of the tram with wheels, the application of corves and rolleys took place; and although it soon became the custom for a single corf upon its rolley to be drawn by one horse, yet, with the exception of the introduction of metal and iron rails, little improvement subsequently took place until within a comparatively recent period.

The first step in advance was the attachment of several rolleys together, each rolley carrying at first one, and afterwards two corves, a horse-load becoming, as the ways improved, four or six corves of 6 cwt. of coals each.

Corves were found, however, to be both expensive and clumsy; and about the year 1835 coal tubs, in pretty much their present form, were generally introduced, the only difference, in fact, being that they were at first constructed with sharp-edged tram wheels, instead of flanched wheels, as at present. The tubs attached to their wheels were placed upon rolleys, capable of carrying two or three at a time, and drawn by horses to the shaft: upon well-constructed rolleyways, a horse-load by this means was usually from eight to ten tubs, although in some instances eighteen or twenty.

About the year 1841 or 1842 the plan of drawing the tubs along the rolleyways to the shafts upon their own wheels suggested itself, which is the plan now adopted, thus very nearly returning to the single-corf rolley, or more remote sledge on wheels

above named. The advantages resulting from this change are very great, for not only can a horse draw a greater number of tubs by not having the dead weight of the rolley to draw, but, what is perhaps of greater value in practice, in case of accidents from tubs getting off the way, much less damage is done in the first instance, and much less time lost in putting matters right.

One of the greatest improvements in the method of bringing out coals from the hewer to the horse road consists in the substitution of small ponies of ten or eleven hands in height for barrowmen or putters, the ponies drawing each one tub at a time, and being managed by boys from fourteen to fifteen years of age. The chief saving is in working to the dip, the ponies being able to bring out their load in moderate inclinations, where with putters extra assistance would be necessary.

Machinery is now much employed in the transit of coals underground, and the form of engine generally best adapted to such work consists in having two horizontal cylinders: when required for a level plane, it is fitted up with two drums (plate 61), and when for a downbrow, or dip-inclined plane, one drum only is necessary. Each drum must be provided with a brake, and with apparatus for putting it in and out of gear.

Engines similar in construction to the above are frequently and very conveniently worked by means of compressed air, which is forced down into the mine by machinery placed at the surface.

When the engines are worked by steam, they are frequently supplied from boilers placed at the surface, the steam being piped down the shaft. It is found that there is exceedingly little loss of pressure with proper care; probably not more than 1 lb. per square inch in a distance of 500 yards.

The use of wire ropes and of endless chains has each its advocates; and this question has been ably investigated, and the results given at great length, in the Transactions of the North of England Institute of Mining Engineers, vol. 17.

When applicable, the cheapest method of conveyance is by self-acting inclined planes: they may be introduced under any circumstances where the inclination is not less than 1 in 36; or, if very great care be used in their construction, 1 in 40.

As regards the ordinary labour of separating the coal from the mine, notwithstanding that many attempts have been made to apply machinery to this purpose (the best contrivance for this purpose being probably the hydraulic machine of Mr. Samuel Parker Bidder, jun., described in the Proceedings of the Institution of Civil Engineers, vol. 28), few practical improvements have been effected since the commencement of working coal: as regards the size of the coals produced, the reverse of improvement has generally been the result. The pick, the maul, and the wedge, are the same tools which (made of different, mayhap of a better material) were employed in the days of William the Conqueror. Facilities have certainly been given to the increase of quantity, by the use of gunpowder, but at the expense of a much greater quantity of small coal

made and wasted, and of a much more friable and shattered state of the large coal obtained.

A machine was, as I have heard, invented by the late Mr. William Brown, of Benton, and called in common parlance "Willie Brown's Iron-man;" but as this instrument only did the work of one man, and required three or four to work it, the economy of its use was not so obvious as to bring it into general favour.

Mr. Waring, of Neath Abbey, in Glamorganshire, about the year 1850 patented a coal-cutting machine, and since then several others have been produced which, in preparing coal for bringing down with wedges, powder, or otherwise, cause considerably less waste than the ordinary method of undermining with picks.

It is as yet premature to express any decided opinion upon the merits of these contrivances.

4. COPPER, LEAD, TIN.

In commencing a copper mine from the surface, a vein or portion of a lode containing ore is seldom met with at a less depth than 10 or 20 fathoms from the surface. A shaft is first sunk, and at about 10 fathoms in depth, a horizontal level or gallery is driven by two sets of men working in opposite directions, the ores and stuff being raised by a windlass. When this level is driven about 50 fathoms, two shafts are sunk at either extremity for airing the mine. This level can be carried to any extent. The engine shaft being sunk deeper, similar levels are driven at every 10 fathoms in depth, the shaft being always sunk to a greater depth than the lowest level. The mine being thus divided into right-angled masses of 50 fathoms in length and 10 in height, these masses are again subdivided by small perpendicular shafts or winzes into masses of about 10 fathoms in height and 16 in length—the mine being finally divided into pitches.

Levels are about 3 feet wide and 6 or 7 feet high, and cut in the body of the vein.

Each pitch is now let to a tributer, who, with his para or gang, break, raise, and pay for dressing the ores, the weekly or monthly produce being made into heaps of about 100 tons each.

Samples of it are sent to assayers to determine the value according to the produce or quantity of fine copper contained in 100 parts of ore, and the samplings are then sold at the weekly ticketings, and the tributers receive a certain share of the value of the ores for their labour. The tributer may not for many months earn a remunerating profit; but if the indications of the lode be favourable, he will at every letting renew his bargain, in the hope that the lode may eventually become rich. If, before the completion of his term, his expectations become realised, he and his gang are often able to work out ore to the value of £60 to £100 each, sometimes more; but at the next renewal the rate of tribute is re-adjusted, and fair wages earned until the lode fails.

Should the pitch or compartment turn out bad, the miner at any time has a right to abandon his bargain, by paying a fine of 20s. The quantity of timber used annually in the Cornish and Devon mines is very considerable, amounting to about £50,000, and consisting almost entirely of Norwegian pine.

The discovery of gunpowder formed a grand epoch in the history of mining, but it is difficult to ascertain the exact time when blasting first came into use among the Cornish miners. It was first used in Hungary and Germany about 1620, and was introduced into England at the Ecton Copper Mine by German miners brought over by Prince Rupert. It was not known in Somersetshire until the year 1634, after which it was introduced into Cornwall. The annual quantity of gunpowder used in the Cornish mines has been estimated at 300 tons of 2,000 lbs. each. (Watson's Compendium of British Mining.)

The ores of lead and tin being found lying in a similar position to those of copper, are worked in the same, or nearly the same manner as above described.

Plate 22 is a plan of part of the workings of the silver-band lead mine at Cronkley, in the manor of Lune, in Yorkshire.

CHAPTER VII.

ON THE GASES AND VENTILATION OF MINES.

BY J. J. ATKINSON AND G. C. GREENWELL.

It appears that the volume of air inhaled by a man is 27·8 cubic feet per hour.

The lungs absorb scarcely any nitrogen and only three parts of oxygen out of every hundred parts of atmospheric air: thus the air expired contains only seventy-nine per cent. of nitrogen and eighteen per cent. of oxygen. The three parts of oxygen are replaced by their equivalents in carbonic acid and in vapour of water. (Annales des Mines, first series, vol. 10.)

Thus 150 workmen, employed in a mine, in eight hours will inspire 33,301 cubic feet of air, which is equal to about 70 cubic feet per minute: they will absorb in the act of respiration 999 cubic feet of oxygen, and restore to the bulk the same volume of carbonic acid, and nearly 3,765 cubic feet of nitrogen, which will remain in excess over the proportions of the common air. (Ponson, Traité de l'Exploitation des Mines de Homille, second edition, vol. 2, p. 5.)

According to Sir Humphrey Davy and Dr. Henderson, about 5 cubic inches of nitrogen are consumed every minute by an ordinary sized man. Allen and Pepys say that azote is given out by the lungs; and Ellis has laboured to show that in respiration the natural nitrogen of the atmosphere is untouched in quantity and unchanged in quality.

The combustion of candles or lamps absorbs a quantity of oxygen which depends on the nature and weight of the substance burnt in a given time. There are at the same time produced carbonic acid and vapour of water. Lamps, such as are usually employed in coal mines, require, in order to support their combustion, from 8 to 10 cubic feet of air per hour.

The oxygen of the air is also absorbed by the horses employed in the mines, as well as by the chemical decomposition of many substances which are ordinarily found in such situations.

Thus under the combined influences of air and moisture, sulphurets are transformed into sulphates, as in the case of iron pyrites which we find transformed into sulphate of iron: and we know that vegetable and animal matters in the same

circumstances undergo a putrid fermentation in which the oxygen of the air disappears, combining with some of the elementary principles of these substances, the products being dissipated into the surrounding atmosphere: these are chiefly carbonic acid gas, carbonic oxide or white damp (?), gaseous compounds of carbon and hydrogen, nitrogen and ammonia. These gases are mixed with other substances, which chemical analysis has been unable to isolate: they have usually a sickly odour, and exercise over people who respire them an action in the highest degree deleterious: they have received the name of miasmata.

The gases due to the chemical decomposition of certain other substances are principally those which are formed by the deflagration of the powder employed in the working of the mines; varied, most probably, by the charge of powder, and perhaps also as it is more or less damp, and the combustion consequently more or less perfect, they form a composition of carbonic acid, carbonic oxide, nitrogen, vapour of water, carburetted hydrogen, and a little sulphuretted hydrogen.

The solid products of the deflagration, which are composed of unburnt powder, sulphate of potash, and sulphuret of potassium, are projected in very minute particles into the surrounding air, which is obscured by them. The fumes of powder, blasting powder especially, have a disagreeable odour, and powerfully irritate the organs of respiration; consequently it is necessary to expel them by the prompt renewal of the air in the place where the blasting has taken place.

The gases met with in mines which, when insufficiently diluted with atmospheric air, are productive of deleterious effects upon the workmen, or capable of forming with it an explosive compound, are as follows:—

1. *Carbonic acid*, called also stythe or black damp.
2. *Dicarburet of hydrogen*, or light carburetted hydrogen, called also fire-damp: mixed occasionally with carburet of hydrogen, or heavy carburetted hydrogen, or olefiant gas, according to some Continental authorities.
3. *Sulphuretted hydrogen*, rarely.
4. *Carbonic oxide* (?) or white damp.

1. Carbonic Acid consists of 2 atoms of oxygen and 1 atom of carbon: its specific gravity, as compared with air,[1] is 1·52901; the weight of a cubic foot is 0·123433 lbs avoirdupois (Regnault): water absorbs nearly its own volume of this gas: caustic alkalies and alkaline earths absorb it very rapidly. It is unfit for the support of combustion and respiration: atmospheric air mixed with one-tenth of this gas becomes unfit for the support of combustion, and lights burn badly in an atmosphere containing from 5 to 6 per cent. of this gas: air containing about 8 per cent. of carbonic acid cannot be respired without danger. This gas appears to act on persons who respire it in the same manner as poisons, and it is necessary, in order to prevent

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[1] Barometer 29·922 inches, thermometer 32°, and a cubic foot of air = 0·080728 lbs. avoirdupois. (Regnault.)

its effects being fatal, that persons asphyxiated by this gas should remain in it for a very short time: when they recover from it, they remain unwell, usually suffering from violent headaches for some days.

Carbonic acid is in many mines disengaged from the fissures and cavities in the strata, and is found, moreover, to result from the respiration of the workmen and horses, and also from the combustion of lights and deflagration of gunpowder.

On account of its great specific gravity, carbonic acid has a tendency to accumulate in greater quantity in the low parts of all excavations, notwithstanding the general property possessed by gases of intermixing or diffusing themselves throughout each other, when contained in any isolated space.

2. Dicarburet of Hydrogen is composed of 1 atom of carbon and 2 atoms of hydrogen: its specific gravity is 0·5619, and the weight of a cubic foot is 0·045361 lbs. avoirdupois (Regnault): it is insoluble in water, and is not absorbed by alkalies. When mixed with atmospheric air in the proportion of from 1-30th to 1-15th of the total volume, the flame of a candle plunged into the mixture is elongated as the proportion of inflammable gas approaches 1-15th of the volume. The flame of the wick is surrounded by a halo of pale blue, which is most perceptible towards the point. The combustion only takes place around the wick of the candle, and does not extend to the surrounding mass. When the fire-damp forms 1-14th of the total volume, the inflammation extends throughout the whole aëriform mass, but without loud detonation. The rapidity of the inflammation increases with the proportion of the inflammable gas until it amounts to 1-10th or 1-8th of the total volume: in these latter proportions, the mixture is explosive in the highest degree. If the proportion of fire-damp is increased still further, the mixture becomes less and less explosive; and when the mixture contains more than one-third of its volume of gas, it is no longer inflammable, but any flame immersed in it is, on the contrary, extinguished by it.

The contact of iron at a red heat is not sufficient to produce the inflammation of fire-damp mixed with air: the presence of flame is necessary.(1)

Nitrogen or carbonic acid, added even in small proportion to an explosive mixture of air and fire-damp, weakens or even prevents explosion—one-seventh of carbonic acid to a mixture the most explosive, sufficing to render it the contrary. We have,

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(1) This, the generally received opinion, ought not to be too confidently relied on, as is shown by the following experiment, made by Messrs. R. Simpson and Greenwell, at Towneley Colliery, near Newcastle-upon-Tyne, May 27th, 1853:—

The gas experimented on passed through a drowned drift in the Three-quarter seam, and was conveyed by means of a pipe in the shaft to the surface: it then passed through naphtha into a gasometer, and thence to various burners in the shops and elsewhere. There was also a cock between the top of the shaft and the naphtha vessel, whence when opened the gas issued in its natural state. The first experiment consisted in placing a bolt, about 2 inches in diameter and heated to a cherry red, in contact with the naphthalized gas in the smith's shop. The gas was immediately inflamed: in a short time, however, the iron, still at a good red heat, ceased to possess the power of exploding the gas. Precisely the same effects were produced when the iron was applied to the gas issuing from the cock between the pit and naphtha vessel. (Transactions of the North of England Institute of Mining Engineers, vol. 1.)

however, from observation, formed the conjecture that certain mixtures of fire-damp and air, rendered inexplosive by the admixture of carbonic acid, may, under certain conditions, be again rendered explosive by a further addition of fresh air : the carbonic acid which formed one-seventh in bulk of the most explosive compound, forming a less proportion of the still explosive compound of fire-damp with the additional quantity of air.

Dicarburet of hydrogen mixed with atmospheric air can be respired for a considerable time without danger, so long as it constitutes less than one-third part of the total volume : beyond this proportion it causes asphyxia by insufficiency of oxygen.

Light carburetted hydrogen is disengaged from the mud in marshes and from all stagnant waters, whence it may easily be obtained by stirring up the mud with a stick, and placing an inverted bottle full of water over the bubbles as they rise.

In some localities, fire-damp flows from the fissures of the soil, and gives rise to natural fires which exist in many places. Borings executed in exploring for rock salt have sometimes produced abundant jets of this gas.

But it is principally found in mines of coal, escaping from the cells of this mineral with a slight noise, analogous to that produced by water immediately before boiling. It is generally disengaged in the greatest abundance in places which are in the neighbourhood of faults, near which the nature of the coal is often found to be altered. There are also in the interior of coal beds, cavities where the gas is pent up under considerable pressure, and from which it escapes suddenly whenever the side of the cavity nearest to the workings is weakened by their approach so as no longer to be able to withstand the internal pressure.

The following facts have been recorded of the volumes and pressures of gas yielded under circumstances of this nature at Walker Colliery, near Newcastle-on-Tyne. (See Report on the Ventilation of Mines and Collieries, by John Phillips, Esq., F.R.S., page 8.)

The first was experienced November 13th, 1846 : on this occasion a mass of coal was displaced 8 feet long on one side, 4 feet on the other, and nearly 6 feet thick : this, with the disintegrated or danty coal which left the slip must have weighed about 11 tons. A discharge of fire-damp ensued : the two men working in the place secured their lamps (one of which had been partially covered with the fall of coal, but continued to burn—the other—nearest the issue of gas—had been put out), drew down the wick of that which continued to burn, hastened to apprise the other men in the pit, extinguishing the lamps as they proceeded, and finally retired to the shaft. The extent of airways fouled at the same time contained about 41,681 cubic feet, and in from 15 to 20 minutes after the eruption there were no longer any traces of fire-damp. The air moved in this part of the mine at the rate of 6·24 feet per second, the quantity passing being 10,483 cubic feet per minute.

A second discharge of fire-damp took place on the 10th December, 1846, at a different point of the same slip: in this case the gas came off from the danty coal with a violent noise, like the blowing off of high pressure steam, and fouled the air courses for an extent of 641 yards in length with a cubical capacity of 86,306 feet. The air was circulating at the rate of 5½ feet per second, and the quantity of air was about 16,000 cubic feet per minute. After 12 or 15 minutes all appearance of gas had ceased, excepting near the point of issue of the blowers.

A similar discharge to that at Walker was the cause of the explosion at Jarrow Colliery in the year 1830. (*See* Mr. Buddle's account of this explosion in the Transactions of the Natural History Society of Newcastle-upon-Tyne, vol. 1.)

According to Sir H. T. de la Bèche and Dr. Lyon Playfair (Report on Gases and Explosions in Collieries, 1846), the analyses of fire-damp obtained from the coal mines of the North of England presented the following results:—

CONSTITUENT PARTS.	WALLSEND FROM PIPE ON SURFACE.	WALLSEND BENSHAM SEAM.	JARROW BENSHAM SEAM.	HEBBURN BENSHAM SEAM, 161 FATH.	JARROW LOW MAIN SEAM.	GATESHEAD OAKWELLGATE FIVE-QUARTER SEAM.	JARROW FIVE-QUARTER SEAM.	COAL 24 FEET BELOW BENSHAM SEAM, HEBBURN.
Dicarburet of hydrogen	92·8	77·5	83·1	86·0	79·7	98·2	93·4	92·7
Nitrogen	6·9	26·1	14·2	12·3	14·3	1·3	4·9	6·4
Oxygen	0·0	0·0	0·6	0·0	3·0	0·0	0·0	0·0
Carbonic acid	0·3	1·3	2·1	1·7	2·0	0·5	1·7	0·9
Hydrogen....................	0·0	0·0	0·0	0·0	3·0	0·0	0·0	0·0
Total...............	100·0	104·9	100·0	100·0	102·0	100·0	100·0	100·0

The general result of this examination is, that the only inflammable constituent present in the explosive gas of these collieries is dicarburet of hydrogen. There is not a trace of olefiant gas, and only in one of the eight gases analysed is there any hydrogen.

When dicarburet of hydrogen cannot be procured from its natural source, it may be obtained artificially by distilling in a coated glass flask, at a red heat, the following mixture:—

1 part stick potassa.
1 part dried acetate of soda.
1½ part quick lime.

All rubbed to powder, and well dried.

It is necessary in this place to make some remarks upon the carburet of hydrogen or olefiant gas, one atom of which is composed of 2 atoms of carbon and 2 atoms of hydrogen: its specific gravity is 0·98528, and the weight of a cubic foot is 0·079540 lbs. avoirdupois (Regnault). It burns with a red flame, of which the illuminating

power is much greater than that of dicarburet of hydrogen. A considerable quantity of this gas is contained in that obtained from coal by distillation (or common street gas), as appears from the following analysis by Dr. Henry :—

NO.	CONSTITUENTS IN VOLUME.				
	SPECIFIC GRAVITY.	OLEFIANT GAS.	FIRE-DAMP.	CARBONIC OXIDE.	HYDROGEN.
1	0·620	12	64·53	7·33	15·84
2	0·630	12	57·49	13·35	17·16
3	0·500	7	55·80	13·95	23·25

Common gas, from its mixture with olefiant and hydrogen gases, is much more inflammable than fire-damp, being easily ignited by iron at a low red heat.

It results from the analyses of M. Bischoff, of Bonn, that olefiant gas is mixed with the fire-damp of certain coal mines—a circumstance which has led this chemist to conclude that the inflammable gases of coal mines are mixtures in different proportions, according to locality, of fire-damp, olefiant gas, and also of other gases in small quantity.

M. Bischoff has not been able to detect olefiant gas in the inflammable gases of the mines of Gerhard and Wellesweiler, in the coal basin of Saarbrück, except in such small quantities that the result might be attributed to an error in his analysis. It is not the same with the inflammable gas produced in a pit sunk in the principality of Schaumburg, in the coal formation of the lias. Here the absorption by chlorine mixed with the gas in an opaque glass flask was considerable, and the endiometric analysis indicated not less than 16 per cent. in volume of olefiant gas, 79 per cent. of fire-damp, and 4·79 per cent. of other gases. Besides, the wire-gauze capable of arresting the flame of the gas collected in the basin of Saarbrück, was not sufficiently fine in its texture to stop the flame of the gas obtained in the pit at Schaumburg, and the miners of this locality were, in consequence, obliged to use lamps constructed with gauze finer in the mesh than that of those used in other coal districts.

The actual constituents of the above three gases were as follow :—

LOCALITIES.	OLEFIANT GAS.	FIRE-DAMP.	PROBABLY NITROGEN.
Gerhard..................................	1·98	83·08	14·94
Wellesweiler	6·32	91·36	2·32
Schaumburg	16·11	79·10	4·79

(Mémoire sur l'Aérage des Mines, by M. Gustav Bischoff. Recueil de mémoires et de rapports publié par l'Académie Royale des Sciences et Belles-Lettres de Bruxelles, 1840.)

Particular experiments have been instituted by Professor Graham on this subject, a notice of which was contained in the "Mining Journal" of June 13th, 1846, from which the following is an extract:—

Killingworth gas: specific gravity		0·6306
Dicarburet of hydrogen	82·5	
Nitrogen	16·5	
Oxygen	1·0	
		100·0

79 measures of this gas mixed with an equal volume of chlorine, left in the dark for 18 hours, and afterwards washed with alkali, were reduced to 75 measures, from which the presence of 4 measures of olefiant gas might be inferred; but in a comparative experiment made at the same time on 25·3 measures of pure gas of the acetates mixed with an equal volume of chlorine, a contraction occurred of 1·3 measure, which is in exactly the same proportion as with the fire-damp. It was observed that phosphorous remains strongly luminous in this gas mixed with a little air, while the addition of 1-400th part of olefiant gas, or even a smaller proportion of the volatile hydro-carbon vapours, destroyed this property. Olefiant gas and all the allied hydro-carbons were thus excluded.

This, I think, coupled with the results arrived at by Sir H. de la Bèche, Dr. Lyon Playfair, Turner, Sir H. Davy, and several other skilful analysts, must be considered conclusive upon this point as regards the fire-damp of English coal mines yet experimented upon. The question, however, should not be considered as finally disposed of.

3. Sulphuretted Hydrogen.—This gas is characterised by the odour of rotten eggs. It is composed of 1 atom of sulphur and 1 atom of hydrogen: its specific gravity is 1·177, and the weight of a cubic foot is 0·0950168 lbs. avoirdupois (Regnault). It is soluble in water, which is capable of absorbing three times its volume of this gas: alkaline solutions absorb it rapidly: chlorine decomposes it, by combining with the hydrogen and causing the sulphur to be deposited. Mixed with air, it takes fire at the approach of flame, the products of the combustion being water and sulphurous acid.

When present even in small quantity in a gaseous mixture it blackens the white oxides of lead and bismuth, which enables us easily to detect its existence. It is sufficient to expose to the mixture in which it is contained, slips of paper which have been dipped in a solution of acetate of lead, and allowed to dry.

It exercises upon the animal economy an influence deleterious in the highest degree: a bird perishes in air containing 1-1500th part of its volume of this gas: 1-800th part is sufficient to kill a moderate-sized dog, and 1-250th part will destroy a horse.—(Thénard.)

The later researches of M. Parent Duchâtelet would, however, seem to show that the poisonous effects of this gas have been somewhat exaggerated, at least in the

application of these results to man. He observed that workmen breathed with impunity an atmosphere containing 1-100th part of sulphuretted hydrogen, and he states that he himself respired, without serious symptoms ensuing, air which contained 3 per cent.

An atmosphere containing from 6 to 8 per cent. of this gas might speedily kill; although nothing certain is known of the proportion required to destroy human life. (Taylor, Manual of Medical Jurisprudence.)

This gas is formed whenever sulphur in a very comminuted form is brought into contact with hydrogen in a nascent state. Thus it may form in mines where there is a decomposition of iron pyrites. It has been met with in old colliery workings, but its occurrence is rare.

4. Carbonic Oxide.—This gas consists of 1 atom of oxygen and 1 atom of carbon: its specific gravity is 0·9762, and the weight of a cubic foot 0·078807 lbs. avoirdupois (Regnault).

According to the recent work of M. Leblanc, carbonic oxide produces upon the animal economy an action more deleterious than that caused by carbonic acid. It burns with a beautiful blue flame, and gives out but little light: when mixed with common air it does not explode like fire-damp, but burns brilliantly; and from this circumstance it appears that a portion of this gas, contained in any atmosphere, might produce a compound in which a candle would burn brightly, but in which human life must become quickly extinct: and we are very strongly of opinion that there exist instances of this nature, some fatal accidents having occurred, the causes of which appear to be almost unaccountable excepting upon this supposition. (*See* Report on Accidents in Coal Mines, 1835, p. 55.)

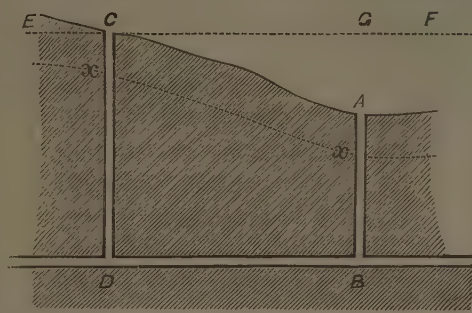
From the properties of the gases above described we may (excepting in the case of carbonic oxide) penetrate without danger into any atmosphere which we find to possess no disagreeable odour; which will not blacken acetate of lead; and in which a safety lamp will burn with facility: but as, even under all these conditions, the atmosphere may, from the presence of carbonic oxide, be unfit for respiration, we are led to the only practically safe conclusion—viz., that we should under all circumstances be accompanied by a sufficient circulation of fresh air, the means of obtaining which we propose to treat of in the following order:—

1. Natural Ventilation.

2. Artificial Ventilation.
   - *a* By *Waterfall.*
   - *b* By *Furnace.*
   - *c* By *Steam Jets.*
   - *d* By *Machinery.*

1. NATURAL VENTILATION.

When we have two shafts of unequal depths to the same level underground, we have in general a natural circulation of air established, the direction of which, excepting under peculiar circumstances, is from the surface of the most shallow of the two shafts at the point marked A in the marginal diagram to the bottom of that shaft marked B in the diagram—through the underground workings, to the bottom of the deepest shaft marked D, and up that shaft to the surface of the earth marked C, where the current is discharged into the open atmosphere: the reason being that there is at a certain depth (x in the diagram) below the surface of the earth (as has been stated in treating upon the internal heat of the earth) a plane where the temperature of the earth remains constant during all changes of atmospheric temperature; and this constant temperature closely coincides with the mean annual temperature that prevails at the place where the shafts are sunk, and that below this undulating plane, which nearly follows the contour of the surface of the earth, the temperature increases (although more or less variably) with the depth beneath it, and hence there is a higher average temperature, and consequently a lighter vertical column of air, as a general rule, in the deep shaft C D (length for length) than in the more shallow one A B, when the surface temperature is as low or lower than that of the air in the deeper shaft.



But as the temperature of the outer atmosphere rises, the downcast column becomes warmer and lighter, reckoned from the top of the highest shaft, and so more nearly of the same density as that of the air which has circulated through the mine: and since the propelling force, causing the ventilation, arises from the density of the equally long column of air in the shallow shaft combined with that of the atmosphere above it, up to the level line E F (at the point G) on the same level as the top of the deeper shaft C D, being greater than that of the column of air in the deeper shaft C D, it follows that as the atmosphere at the surface G to B becomes warmer and lighter, while the air in the deeper shaft C D remains nearly constant in temperature and density, owing to the natural temperature of the rocks and minerals remaining so, the propelling force becomes reduced, and hence also the quantity of air circulated through the mine in a given time: and when so great a reduction of density is produced as to cause the column of air G A B to be upon the average no greater than that from C to D, ventilation is altogether suspended. It may even happen to occur, particularly in shallow shafts, or where there is an adit and a shaft, that in very hot weather the direction of the ventilating current may become reversed.

There is no need to consider the density of the atmosphere above the level line E F, inasmuch as it will exercise the same pressure on each unit of surface in each of the connected shafts or adits, excepting under peculiar circumstances.

In deep mines, where the air by contact with the rocks and minerals and other sources of heat frequently becomes heated to a temperature considerably above the mean annual temperature of the outer atmosphere, or, as in some cases, equals that which prevails in the hottest summer, natural ventilation may continue uninterrupted, and in the same direction throughout the course of the year, after it is once established.

The rationale of the motion of a column of air under such circumstances will be explained shortly.

Natural ventilation, however it may be found effectual in deep mines, having few ramifications, accompanied by freedom from inflammable or noxious gases, is quite inadequate to keeping in a safe and healthy state mines where these gases abound: not only on account of its comparative feebleness, but on account of its liability (especially in mines of moderate depth) to be disarranged by changes of atmospheric temperature.

We ought to have, at all mines, artificial means of producing ventilation at hand—not necessarily for constant use in some cases, but always ready for action in the event of the natural ventilation becoming too much diminished from any cause whatever.

This leads to the consideration of the various modes that are employed to produce

2. ARTIFICIAL VENTILATION.

a. The Waterfall.—A circulation of air through a mine may be produced by allowing water to fall down the downcast shaft; but if the water has to be raised to the surface again by steam power from having no natural adit or outlet at a lower level, this is a very expensive mode of producing ventilation, and probably seldom economises so much as 10 per cent. of the power required to raise the water from the bottom to the top of the shaft after it has done its work; yet it is often a ready resource for obtaining a moderate amount of ventilation, in the case of explosion and some other classes of accidents; or when a furnace, fan, or other apparatus, is undergoing repairs.

The effect of a waterfall, consisting of a quantity of water passing through two holes 1 inch in diameter each, and falling 63 fathoms (the full depth of the pit), may be judged by the following experiment made at Blackboy Colliery, May 8th, 1845. The colliery was at this time ventilated by a 9 feet furnace, and the experiment was made in one of the working districts, previous to, and after, subdividing the portion of air applied to its ventilation:—

1. Before splitting the air.

	CUBIC FEET.	
The quantity passing into the district with the furnace alone, was	8,394	per minute.
After putting on the waterfall, it was	11,565	„
Increase due to waterfall	3,171	„

2. After splitting the air.

	CUBIC FEET.	
The quantity passing into the district with the furnace alone, was	11,313	per minute.
After putting on the waterfall, it was	13,687	„
Increase due to waterfall	2,374	„

The reason of this reduced increase will be seen hereafter when we enter upon the question of resistance.

The following experiment made at Norwood Colliery, where the depth of the fall was 80 fathoms, also allows us to compare the effect of a waterfall with that of a furnace (June 22nd, 1850):—

	CUBIC FEET.	
The quantity of air passing into the district with the furnace alone, was	9,000	per minute.
After putting on the waterfall, it was	10,590	„
Increase due to waterfall	1,590	„

Ventilating a mine by a waterfall produces a dampness in the air near to the shaft bottom which causes the timber used in propping and upholding the roof, &c., to decay rapidly.

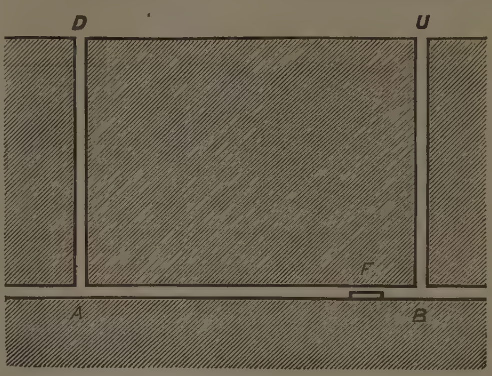
b. THE FURNACE.

The system of ventilation usually adopted in England, more especially until a few years ago, and in Belgium at a much earlier date, consists of a furnace or fire in the vicinity of the upcast shaft: in small mines furnaces are sometimes placed on the surface and surmounted by a chimney, but this plan only generates a limited pressure and circulation of air, at a great cost in fuel, as compared with the more ordinary and recent mode, which consists in placing the furnace underground, so that the upcast shaft itself forms the chimney, and creates a very much stronger draught from its length being generally much greater than that of the chimneys connected with furnaces employed at the top of upcast shafts.

The effect of the furnace in creating a current of air in mines, arises from the expansion and consequent lessening of the density of the air in the upcast shaft by the additional temperature imparted to it, over that prevailing in the air of the downcast shaft.

By way of general and short explanation, let us take a case where the top of the downcast shaft D A is on the same level as that on the top of the upcast shaft U B;

the bottoms of the shafts being in open communication with each other, by means of a horizontal or level drift A B, in which, at F, near the bottom of the upcast shaft, a furnace is in operation to heat the air column in the upcast, and to expand and cause it to become lighter, bulk for bulk, than that descending the downcast shaft.



The result of the above arrangement would evidently be that the insistent weight of air upon any given area of horizontal section at the bottom of the upcast shaft would be rendered less than that upon an equal area of section at the bottom of the downcast shaft, because the pressure of the upper atmosphere above the tops of the shafts would be the same upon each unit of sectional area, while the weight of a column of air in the upcast shaft would be less than that upon an equal area of section in the downcast shaft.

The reduction of pressure per unit of surface so produced in the upcast shaft would of course destroy the balance, and the excess of pressure in the downcast shaft would force a current of air through the connecting drift or workings to and over the furnace, where it would become expanded, and this continuous excess of pressure per unit of surface prevailing in the downcast over that prevailing in the upcast shaft would endure, so long as the furnace was kept burning, and thus cause a circulation of air through the mine or the drift connecting the shafts.

Now, since air expands with every additional degree of Fahrenheit's scale 1-459th part of its volume at zero, or at 32° below the temperature of melting ice, the mode of finding the height of the head or motive column of air of the same density as the air descending the downcast shaft is expressed by

$$H = D\left(\frac{T-t}{459+T}\right) \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (1)$$

Where H = head of the motive column in feet.
D = depth of the shaft in feet.
T = average temperature of the air in the upcast shaft.
t = temperature of the air in the downcast shaft.
459 = the constant number already mentioned, based upon the results of the best experiments that are known in reference to the subject—those of Magnus and Regnault—some petty fractions only being ignored.

Were it not the fact that currents of air moving in contact with stationary bodies meet with resistance, then the velocity with which the air would move would be the same as that which would be acquired by a body falling freely under the force of gravity through the height H, and would consequently be expressed by

$$v'' = \sqrt{64\tfrac{1}{3}\,H} \text{ in feet per second} \dots \quad \dots \quad \dots \quad \dots \quad (2)$$

Which is the same as

$$v'' = 8{\cdot}0208\sqrt{H} \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (3)$$

But if the velocity were (in the absence of friction) to be taken in feet per minute $= v'$, then by

$$v' = \sqrt{231{\cdot}600\,H} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (4)$$

or in another form, by

$$v' = 481{\cdot}2\sqrt{H} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (5)$$

Now, the weight of a cubic foot of air, as deduced from M. Regnault's able and delicate experiments, in this latitude and at sea level is expressed by

$$w = \frac{1{\cdot}32529\ B}{459 + t} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (6)$$

and hence the weight of 100 cubic inches of dry air expressed in grains may be found by

$$\underset{o}{w} = \left(\frac{1{\cdot}32529\ B}{459 + t}\right) \times \left(\frac{7000 \times 100}{1728}\right) \text{or by its equivalent, viz :—}$$

$$\underset{o}{w} = \frac{536{\cdot}865\ B}{459 + t} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (7)$$

Where w = the weight in lbs. of a cubic foot of dry air at the pressure B (expressed in inches of the density due to the temperature of 32° on Fahrenheit's scale, being that of melting ice)—the lb. being avoirdupois and equal to 7000 grains.

$\underset{o}{w}$ = the weight in grains of 100 cubic inches of dry air.

B = the barometrical pressure under which, as above explained, the air exists.

t = the temperature of the air composing the assumed motive column.

Hence in order to find the pressure in lbs. or grains on each square foot, operating to produce ventilation, we may proceed as follows :—

1st. Find the value of H by formula (1).

2nd. Find the value of w by employing formula (6).

3rd. Multiply the so found value of H by that of w, and the result is the pressure per superficial foot in lbs. operating to produce ventilation, which being denominated P gives

$$P = H\,w \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (8)$$

If, however, it is required to find the pressure in grains per superficial foot, it can be done by multiplying the right hand member H w by 7000 (the number of grains in a lb.), and hence if the pressure in grains per square foot is designated by p, we obtain

$$p = 7000\,H\,w \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (9)$$

In the practice of ventilation the velocities indicated in the formulæ (2), (3), (4), and (5) are never realised, and the true and complete theory embraces the friction of the air, and is deduced from practice.

As instances of the small proportions of the motive column which the generation of the final velocity of the air at the top of the upcast shafts is due to, we have,

from the Transactions of the North of England Institution of Mining Engineers, the following cases cited (volume 3, pages 94, 95, &c.) :—

NAMES OF THE COLLIERIES.	PROPORTION OF MOTIVE COLUMN DUE TO FINAL VELOCITIES.	PROPORTION OF MOTIVE COLUMN DUE TO RESISTANCES.
Hetton Colliery	1	17
Tyne Main Colliery	1	7
Haswell Colliery	1	10

From this it is evident that were it not for the resistances encountered by the air in its passage through the shafts and workings of mines, there would be an enormously increased quantity of air circulated in a given time by the same pressure per unit of surface.

We have now to consider the natural laws which determine the amounts of motive columns or pressures per unit of surface that are required to overcome these principal and most important resistances to the ventilation of mines.

It has been found by many experiments, made specially for the purpose of determining the natural laws on the subject, that if we adopt the following notation, viz.:—

h = the pressure per unit of surface (which we shall assume to be a square foot) of the sectional area of the shafts and airways: taken in a plane at right angles to their axes.

a = the area of the air passage, assumed here to be in square feet.

k = the head in feet of air column (assuming that the air of the imaginary motive column is of the same density as the air flowing in the air passage, channel, or pipe) that is required to overcome the resistances met with when the air passage has the adopted unit of area of one square foot, and the sides of the channel also present an equal area (a square foot) to the air.

Also, in this case, seeing that the lineal foot has been adopted as the unit of distance, the square or superficial foot as the unit of area; (and as it is proposed to take the unit of time as being 1 minute) the unit of velocity will be 1 foot per minute, and the quantity of air passing per minute will be 1 cubic foot, the amount or value of k, the coefficient of resistance, must be exceedingly small in the formulæ about to be given.

s = the area of the rubbing surface against which the flowing air has to glide in its passage through the shafts and workings of the mine, expressed in square feet, as found by multiplying the length by the perimeter of the passage when it is of uniform area and shape of section throughout its entire length; or if of varying areas and perimeters, then let s be taken as the sum of a series of quantities to be found by dividing the passage into distinct lengths having uniform sections, and multiplying the perimeter of each of such lengths by the distances over which they respectively prevail; the sum of these separate products being taken as the value of s, as already stated.

v = the velocity of the air in feet per minute in the case of pipes and passages of uniform area and shape of section over their entire length.

Then, in the case of pipes or passages having an uniform area and shape of section, the following formulæ will obtain with regard to the height in feet of motive column that will require to be expended upon overcoming the frictional resistances, exclusive of and beyond the height required to generate the velocity with which the air has to be expelled into a calm, open atmosphere, after traversing the airways or pipes after commencing from a state of rest:—

Total pressure in feet of motive column ...	$h\,a = k\,s\,v^2$	... ...	(10)
Square feet of rubbing surface	$s = \frac{h\,a}{k\,v^2}$	... ...	(11)
Velocity of air in feet per minute	$v = \sqrt{\frac{h\,a}{k\,s}}$	... ...	(12)
Height in feet of motive column absorbed by resistances alone beyond that which generates the final velocity of the air ...	$h = \frac{k\,s\,v^2}{a}$	... ...	(13)
Area of the section of the airway, pipe, or channel, in superficial feet	$a = \frac{k\,s\,v^2}{h}$	... ...	(14)
Unit or coefficient of resistance, as already defined	$k = \frac{h\,a}{s\,v^2}$	... ...	(15)

By (11) we can find the internal area of the walls of a pipe or airway if we observe the motive column, h; the sectional area of the pipe or airway, a (over any series of separate distances where it is uniform); the velocity of the air in feet per minute, v; and know the value of the coefficient of resistance, k.

By (12), (13), (14), and (15), we can find the values of v, h, a, and k, respectively, when we have observed the values of the other quantities involved in the formulæ. In each case, however, h only represents the portion of the motive column that is required to overcome the resistances, and in none does it embrace that portion which is required to create the velocity with which air, starting from a state of rest, leaves the exit end of the pipe, passage, or the top of an upcast shaft, as found by formulæ (4) or (5).

If, however, from irregularities in the form of section of any pipe or airway, it is requisite to consider the portion of the height in feet of the motive column due to separate lengths of the pipe or air passage, and add them together to get the height in feet of the head of column (supposed to be of the same density as that of the flowing air or gas), it is not necessary to consider the height of motive column due to any change of area of section (so far as velocity is concerned), at the commencement or termination of any such divisions, inasmuch as the velocity, and therefore also the head due to its generation is the same at the end of each division as it is at the commencement of the succeeding one, and the velocity and momentum of the air at the termination of each such division or separate length of pipe or airway is equivalent to the head that would generate the initial velocity of the next succeeding length or division, the first requiring a pressure of a certain amount to generate it, and the latter obtaining exactly the same amount of benefit from its prevalence; so that when

the proper allowances of motive column are made for the existence of sudden contractions, or regulators, in a pipe or airway, we have only to allow for the portion of the head or motive column required to generate the exit or final velocity of the air, at the outlet where it leaves the pipe, airway, or upcast shaft, and is discharged into the open atmosphere; provided that the air enters the pipe, &c., from a state of rest, and is uninfluenced by winds.

When winds affect the air at the top of the downcast shaft, in aid of the ventilating power, it is only any excess of motive column due to the final or exit velocity over that due to the wind that ought to be allowed for; and on the contrary, when the force of the wind is opposed to the entrance of the air into the downcast shaft, an equivalent amount of motive column must be added to that due to the final or exit velocity of the air.

Similar remarks apply to the effects of winds aiding or obstructing the exit of the air at the top of an upcast shaft.

It may here be observed that all the formulæ and laws that have here been given in reference to the resistances met with by air, and the head or motive column required to overcome them, apply equally to street and other kinds of gas, apart from their difference of density; for although the pressures per unit of surface of the motive columns required increase and decrease in the proportion of the densities of air or gases transmitted in equal quantities in a given time through the same channels, the variations are met by the formulæ, which involve the height in feet of the motive column, h—which is taken as being of the same density as the flowing air or gas.

In extensive mines with long runs for the air, and where splitting the air into different currents is but little practised, especially where the upcast shaft is large in area, and comparatively small in the perimeter of its section, as well as in pipes or channels used for the transmission of air or gas, which are generally of great length compared with their sectional area or perimeter of section, the formulæ (10), (11), (12), (13), (14), and (15) apply with all but rigid accuracy, provided that we know the real value of k, the coefficient of resistance as defined previously.

But in cases of mine ventilation where the airways are large in sectional area, and hence comparatively small in perimeter of section—numerous, in consequence of the air being split, or divided into several short currents—but especially when accompanied by a comparatively small exit at the top of the upcast shafts (and similar remarks will apply to the transmission of gas or air through large but short pipes), then it becomes more and more necessary to embrace in the formulæ mentioned an element allowing for the height or portion of the motive column that is employed in generating the exit or final velocity, and all the more so as these conditions become more and more marked in their respective amounts.

In doing so, if we assume h_v to represent, in our assumed unit of length, the head of motive column in feet that is due to the generation of the exit or final velocity of

the air or gas as found by (4) or (5), we should require, in lieu of (10), to employ the following formula :—

$$a\,(h-h_v)=k\,s\,v^2, \text{ or } a=\frac{k\,s\,v^2}{h-h_v} \quad \dots \quad \dots \quad \dots \quad (16)$$

Instead of (11) we should have to use

$$s=\frac{a\,(h-h_v)}{k\,v^2} \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (17)$$

In place of (12) we should require to use

$$v=\sqrt{\frac{a\,(h-h_v)}{k\,s}} \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (18)$$

Instead of employing (13) we would have to use

$$h-h_v=\frac{k\,s\,v^2}{a} \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (19)$$

giving us $h=\frac{k\,s\,v^2}{a}+h_v$ ... ... (20)

In the whole of the foregoing formulæ the chief uncertainty lies in the value of the coefficient k as suited to the differences of materials in contact with which the circulating or flowing air moves, particularly as regards the airways in mines, notwithstanding the few experiments that have been made in England and in Belgium to determine its value.

The results of a host of experiments made by M. Girard with air, and others with common street gas, with the apparatus of St. Louis' Hospital, through old tarred cast iron pipes, and through old rusty sheet iron pipes, in all of which the air and gas were at the ordinary temperatures of the outer atmosphere : the immense number of experiments made with hot air passed through flues and chimneys of baked earth, clay, or of fire bricks, and free from soot; through new and clean sheet iron ; and through sooty cast iron, by M. Péclet: others by M. Rudler, with hot air passed through a channel of cast iron: others by Mr. Hawkesley, by passing street gas through cast iron pipes: and many by M. Girard, with cool air and also with gas, with sheet iron pipes: besides some by M. D'Aubuisson with cool air through tin pipes; give very different values of the coefficient k in our formulæ, the cause of the differences not being very clearly ascertained.

The whole of the above experiments, together with some others made with centrifugal fans, furnaces, and steam jets, appear, however, clearly to indicate that the quantity by volume, and consequently also the relative velocities of air or of common street gas, when a fixed quantity is passed through the same channel in a given time, require equal heights of motive column, reckoned as being of their respective densities; and also that the quantities passed in a given time are sensibly proportional to the square roots of the heights of the motive columns so reckoned.

Notwithstanding what has just been stated, it appears to be somewhat peculiar (judging from the resistances and the pressures required to overcome them) that they should be found to vary greatly in their amount, according to the nature or state of the internal surfaces of the channels through which they move, while that of water

is the same for all classes of pipes, tubes, or channels, the probable cause being that in the latter case a stationary film of water adhering to the interior surface of the passage forms in all cases a similar artificial surface for the flowing water to glide along, although this has not been proved to be the actual cause.

By way of illustrating the foregoing remarks, and for much more important reasons, the following values of k are given as found by different experimentalists, such values of k being suited to the formulæ already given.

TABLE showing the value of the coefficient of friction k, as used in the preceding formulæ; being the height in feet of air or gas column required to overcome the frictional resistances encountered by one cubic foot of air or gas per minute in passing through a passage presenting one foot area of section, and one foot area of rubbing surface to the air or gas when flowing at the rate of one lineal foot per minute: the height of the motive column being calculated as if it were of the same density as that of the air or gas current at the place of observation:—

NATURE OF THE MATERIAL COMPOSING THE PIPE OR AIRWAY.	STATE OF THE INTERNAL OR RUBBING SURFACE PRESENTED TO THE CURRENT.	OBSERVERS' NAMES.	GENERAL TEMPERATURE OF THE AIR OR GAS.	HEAD OF COLUMN OF THE SAME DENSITY AS THE MOVING AIR OR GAS, REQUIRED TO OVERCOME THE FRICTION; BEING THE COEFFICIENT OF FRICTION=K.
Burnt earth	clean	Péclet	hot	·00000026881
Sheet iron (malleable)	new and clean	Péclet	hot	·00000010583 ·00000006773
Cast iron ?	ordinary ?	Rudler	hot	·00000008466
Cast iron	sooty	Péclet	hot	·00000005292
Cast iron	old, tarred	Girard	cool	·00000004870
Gas in pipes (Cast iron.)	ordinary	Hawkesley	cool	·00000003014
Water in pipes (Cast iron.)	ordinary	Eyletwein	cool	·00000003028
Sheet iron	old and rusty	Girard	cool	·00000002696
Tinned iron	?	D'Aubuisson	cool	·00000002540
Galleries of a coal mine ..	ordinary state	Guibal	cool	·00000011759
Galleries of a coal mine ...	ordinary state	Scohy	cool	·00000008992

We have omitted the experiment at Crookbank Colliery in the table, as the details in reference to changes in the area of section of the different parts of the air-way and shafts, and the consequent changes of velocities and of pressures due to such changes of area of section which alter in a much higher ratio than the mere changes of area and velocity (viz., as the squares of the velocities), were not sufficiently well ascertained to give a perfectly reliable value of k. (See foot of page 177 in 1st edition.)

From the facts and formulæ given, it is evident that—

1. The velocity of the current in cases where either natural or furnace ventilation is employed increases with any increase of the average temperature in the air column in the upcast over that in the downcast shaft; because any increase in the motive column is accompanied by a relative increase of this excess of temperature; and other things being equal, its amount depends upon this excess of temperature. Yet, again, in such cases this excess of temperature itself is promoted by any increase of velocity

in the air currents, at least in all ordinary cases where the return air is used for the combustion of the fuel in the furnace, which is the general practice.

Where the return air of a mine is so mixed, or so liable to be mixed, with sudden discharges of fire-damp as to endanger the occurrence of explosion at the furnace, it may, in the absence of other appliances, be expedient to feed the furnace with fresh air from the bottom of the downcast shaft: and in other instances, where the return air is so mixed with carbonic acid gas as to retard combustion, the same remark is applicable: but such cases are rare under ordinary circumstances, and in all cases, excepting in that of carbonic acid gas in large proportion, there will be less air in the workings (because more in the shafts absorbing by the extra friction a larger proportion of the height of motive column) when the furnace is fed by fresh, than when it is fed by return air.

The temperature of the upcast shaft depends to some extent upon the velocity of the air-current, because if, in addition to the use of the furnace, we employ any mechanical or other means, we increase the quantity of air, we shall find the increase to be in a greater ratio than is due to the mere mechanical agent employed, inasmuch as we shall find a higher mean temperature in the upcast, and the motive column increased in a corresponding degree, owing partly to the more fierce combustion of the furnace, and partly to the more rapid travel of the hot air up the shaft, and consequent lessened amount of cooling, whether from conduction, radiation, or other cause, owing to the shorter time that the more rapid current is exposed to such cooling influences, which are of very considerable amount.

On June 23rd, 1853, the following experiments were made by Mr. Greenwell, at Marley Hill Colliery, with a view of ascertaining to what extent this principle was correct: the increased quantities of air were obtained by various alterations in the run of the air between the down and upcast shafts, these alterations occupying the position of additional mechanical means of ventilation :—

	DEPTHS BELOW SURFACE.	TEMPERATURE.			
		Degrees.	Degrees.	Degrees.	Degrees.
1	2 fathoms	91	90½	99½	103
2	10 "	92	91	99½	104½
3	15 "	93½	89½	98	102½
4	20 "	96½	93	104	109
5	25 "	97	92	103	108
6	30 "	97½	95	106	112½
7	35 "	105	102½	117½	125
8	40 "	104	101½	117	125
9	45 "	105	104¾	123½	130
10	50 "	112	105¾	126	135
11	55 "	110	108½	130	140½
12	60 "	122	115	135½	145
13	65 " furnace drift ...	138	136	169½	180½
	Average	104¾	102	117½	124½
Quantity of air in cubic feet ℔ minute		28,588	27,453	30,511	35,403

2. The amount of air circulated by a given motive column in any given time depends upon the number, lengths, and areas of sections of airways, and increases as their lengths are shortened, and as they are made either more numerous or increased in sectional area: the formulæ given show to what extent, but a limited space forbids the illustration of their relative influences by examples. These objects may in a great degree be effected by splitting the air, as it is termed; *i.e.*, by dividing the main current after it descends the downcast shaft into a series of separate or branch currents, each having only a part of the workings to traverse and to ventilate, in lieu of causing the whole current to traverse in an undivided state the whole of the ramifications of the mine.

In splitting the air, two points require particular attention:—

1. Not to carry the splitting too far; or the separate currents will become too feeble, notwithstanding the increase produced by their means in the total quantity of air passing through the mine in a given time.
2. To have large airways in the mine both before the air reaches the points where it is split, and also after the splits of air have been reunited, inclusive of the size of the downcast shaft, and where mechanical ventilation is employed, of the upcast shaft also.

There is, however, a certain size of upcast shaft when furnace ventilation is employed, depending upon numerous conditions, which is even more effective than any either larger or smaller one; but this particular size is not fully determined, and varies with conditions.

If any district of a mine evolves so large a quantity of fire-damp that its being mixed with the rest of the return air would raise the whole current to the firing point, the split of air which ventilates such district must of course be taken into the upcast shaft by some other route than by that in which the furnace is placed. A drift is, therefore, driven in fiery collieries from one of the returns into the upcast shaft, by means of which any division of air which is of a dangerous character may be separately conveyed into it.

The point of delivery into the shaft, of such drift, should not be less than 8 fathoms above the furnace drift end, so as to preclude the possibility of the inflammable gas being ignited by any ascending flame. There are cases in which the whole of the return air must pass into the upcast without contact with any flame, in which case the furnace must be fed entirely with fresh air from the downcast shaft, as already explained.

In order to regulate the quantity or proportion of air which it is desirable to pass through each district, a description of sliding door, in a frame of proper dimensions, is placed in the return airways of such districts, as, in its absence, they would naturally (from their shortness and sectional areas) obtain a larger proportion than they required, in comparison with larger or more necessitous districts. This sliding door is called a regulator or contractor, and the frame may, if necessary, be made of the full size of

the section of the airway: the door is divided vertically about the middle, one-half being fixed and the other half made so as to slide in or out in a groove in the frame alongside of and parallel to the fixed part of the regulator or contractor, in order to alter the area of the air passage through the frame. It ought to be furnished with a lock, or other means of securing the slide in its required position, in order to prevent any ignorant or mischievous person from altering its position, and thereby disturbing the proper distribution of the air.

In all mines generating fire-damp, and consequently requiring an energetic ventilation, the desirability of attending to the matters just mentioned is paramount to every other consideration, to secure safety and economy: for it has been established by the very numerous experiments of Péclet, D'Aubuisson, Girard, Rudler, and others, that the heights of motive columns required to overcome the resistances met with by air, gases, and vapours, in passing through enclosed pipes, and the airways and shafts of mines, increase in the proportion of the squares of the velocities, or that of the squares of the quantities passing in a given time through the same unaltered channels: so that under such conditions (and since the velocities for equal quantities in a given time are in all cases inversely as the sectional areas of the channels) when other things, including the perimeters of the sections of the channel, remain the same, the resistances and the heights of motive columns required to overcome them are inversely proportional to the squares of the sectional areas, the quantities in a given time being the same, while the sectional areas alone are varied.

It is evident that any auxiliary or additional pressure, motive column, or power applied to increase the velocity of a current of air moving through a given channel will produce a less apparent or comparative effect towards that end than would be produced by an equal amount of pressure, motive column, or power applied to increase a current of air moving through the same channel at a lower speed. (See experiments with waterfall, page 219.)

The essentials to produce a good furnace ventilation may be stated to consist chiefly of the following elements:—

1. Powerful means of heating the column in the upcast shaft.
2. Length or height of the heated column, which in shallow mines, where winding is not in operation, may be increased by a tube or chimney of masonry of the sectional area of the shaft, and erected on the surface, over it.
3. Short air courses.
4. Large areas of air channels.

The two latter are also requisite, whatever mode of ventilation may be employed; and both of the last-named elements are greatly promoted by splitting the air; each split only traversing a district or division of the entire workings; and the nearer to the shafts that such splitting of the air, and also that such reunion of the splits takes place, the more efficient will it prove in promoting the ventilation of a mine.

It would be superfluous in this place to state the length or dimensions which

ought to be given to upcast shafts or airways: because the circumstances of all mines are so varied, both as regards their extent and the quantity of air they require in order to their being sufficiently ventilated, that no fixed rule would be found applicable even to any one mine for any great length of time.

The state of dampness or dryness of the upcast shaft is an important element in any attempt to determine the best size of such shafts, as the loss of temperature, and consequently also the height of the motive column, together with the quantity or volume of air put into circulation in a given time, are more or less dependent upon the state of the upcast shaft in this respect.

Some of the arrangements that should be observed in the construction and use of ventilating furnaces, in order to secure the largest amount of ventilation from any furnace of a given area of grate, are as follow:—

The passage over the top of the fire at the front should to a certain extent be capable of being limited in sectional area, so that combustion, and thereby the temperature of the air entering the upcast shaft, may be increased to the maximum, if required: there is, however, a limit in this direction, as any limitation of the section here increases the resistances met with by the air in passing the furnace: trials of the results arising from different degrees of contraction above the furnace bars is perhaps the best mode of ascertaining the proper sectional area.

Furnace fires should be kept thin, and ought not to have the fuel piled up (as we too frequently find), since it prevents the air from passing comparatively freely through the burning fuel, and thus lessens combustion and upcast temperature, while it increases the resistance, and so reduces the quantity of air circulated in a given time.

When a large furnace is required, the form and dimensions shown in plate 62, fig. 1, accompanied by arrangements for front contraction, if required, will be found to work in an efficient manner.

The furnace is most effective in creating ventilation when placed in the lowest position, and as near as possible to the bottom of the upcast shaft; and this may best be accomplished where the shaft is only used as an upcast for the air, and is free from timber, unprotected coal seams, and other combustible materials. But in cases where the shaft is not possessed of these requisites, or is also used as a winding shaft, as well as in cases where a dumb drift is necessary, it should, in order to avoid conflagration, damage to ropes and guides, as well as explosions of fire-damp, and other casualties, be placed at a distance of from 50 to 100 yards back from the bottom of the shaft (involving a waste of fuel, but increasing safety), except in particular cases where the furnace and the heat of the upcast air are comparatively small.

The drift from the furnace to the upcast shaft should have a rising inclination of not less than about 1 in 6, or the smoke is liable to back or regurgitate by the running of cages (when the shaft is used for winding purposes), by the opening and closing of ventilating doors, or by the effects of winds in the open atmosphere at the surface, or tops of the shafts.

If the furnace is placed in the seam of coal, we must not omit an arched flue round it, of the full height of the coal, so as to prevent any conflagration which might arise from the heat of the furnace causing ignition of the coal, a circumstance of by no means unfrequent occurrence.

c. Steam Jets.—In the first report of the North of England Society for Preventing Accidents in Coal Mines, written in 1814, by Mr. Buddle, is a drawing and description of a steam ventilator, in which steam is carried down and discharged in a shaft from a boiler placed at the surface: the steam in this case was delivered downwards into the upcast shaft, and the pressure and ventilation produced by it were due to the steam for reducing the density of the upcast column by the combined agency of increasing its temperature, and its saturation with moisture: leaving the effect so produced as so much addition to any natural or other (artificially created) motive column in operation.

The next attempt at producing ventilation by steam, was made in Wales, by Mr. M. G. Stewart, in the year 1828; but the mode in which it was applied not being found to produce the effect required, its application was abandoned.

The steam blast applied to the locomotive engine having proved so admirably effective in producing that violent draught of air so essential to its wonderful concentration of power, induced Mr. Goldsworthy Gurney to conceive that great benefit would arise from its application in a somewhat similar manner to the ventilation of mines: and we find that in July, 1835, before the parliamentary committee appointed to enquire into the causes of accidents in mines, and in October, 1839, in a letter addressed to the committee of a society at South Shields, established for a similar object, that gentleman explained at length his views upon the subject.

A good and extremely useful mode of applying steam to increase draught and ventilation is that figured in the report of the last named committee (plate 62, fig. 2): it consists of a number of small jets of high pressure steam (in proportion to the area of the section of the shaft and to the pressure and the supply of steam at command) directed upwards in and placed near to the bottom of the upcast shaft.

The application of the steam jet to the ventilation of collieries on a large scale was first made by Mr. T. E. Forster, of Newcastle-upon-Tyne, at Seaton Delaval Colliery, in the year 1848, with apparatus similar to the above.

So much importance having been attached to, and so much powerful evidence before various parliamentary committees having been given in favour of the superiority of ventilation by high-pressure steam, as compared with that by the furnace, the subject has been investigated with the closest scrutiny, and the two powers tested by most careful experiment, by several practical colliery viewers in the North of England —these experiments being detailed at length in the first volume of the Transactions of the North of England Institute of Mining Engineers.

There is no doubt that cases will occur (such for instance as in the early workings of a very fiery seam of coal, or in the re-opening of abandoned mines infested with fire-damp) where the steam jet may be applied with advantage; but as regards the amount of air to be obtained by the furnace and by the steam jet in any form in which it has hitherto appeared, we extract the following quotation from a paper communicated to the Institute by the late Mr. Nicholas Wood:—

> "In conclusion, the practical result of all these experiments is, that within the limits or range of furnace ventilation, the steam jet, acting as a *substitute*, is attended with an increase in the expenditure of fuel of nearly 3 to 1, without any corresponding advantage either in the steadiness, security, or efficiency of ventilation: on the contrary, from its simplicity of construction, the steadiness of its action, its less liability to derangement, its economy, and its efficiency in cases of emergency, the furnace is a more secure, more safe, and more eligible mode of ventilation than the steam jet."
>
> "And with respect to the steam jet as an *auxiliary* to the furnace, the conclusion is, that the increase of the jets over the furnace is quite inconsiderable—that such increase is extremely unsteady, in some cases nothing at all, when the furnace is urged to its maximum effect; and in the ordinary working state of the furnace (supposing the furnace kept within its limit so as to have adequate spare power in case of emergency) amounting to only about 2 or 2½ per cent.: that such increase is, however, attended with a loss of power, or increase in the consumption of coal, as compared with the furnace, of nearly 3 to 1—and taking into account the uncertainty of its action, that the increase of 2 to 2½ per cent. is only obtained when the furnace is about ten per cent. within its maximum power (see experiment, plate 7, and experiment, table 5)—and seeing likewise that when the furnace is urged to its maximum power, in cases of emergency, an increase of ten per cent. can be immediately obtained by the furnace (see experiment, page 68)—it is quite clear that the steam jet is equally ineligible and inefficient as an *auxiliary*, as when applied as a *substitute* for the furnace in the ventilation of coal mines."

It is proper to observe here that some errors were fallen into in interpreting the experiments above-named, as given in several papers communicated to the North of England Institute of Mining Engineers, and these errors tended to exhibit the effects of the steam jet as a ventilator in a much more unfavourable light than the results really warranted. Instead of entering into particulars in any of the instances alluded to, it will suffice to point out the principle, and to show how the errors arose.

If a furnace assisted by any natural increase of pressure and power gave 40,000 cubic feet per minute, and the steam jet were added to these causes of ventilation, and the result was a ventilation of 50,000 cubic feet per minute, then, in the cases mentioned, it was inferred that the steam jets only produced 10,000, or one-fourth of the number of cubic feet per minute that were produced by the previously mentioned other sources of ventilation; while in reality, under such conditions, the steam jet was producing in pressure or motive column 9 parts as compared with 16 parts due to the united effects of the natural and ventilating pressures; or the jets were increasing the previous ventilating power in proportionate numbers from 64 up to 125, the pressures being proportional to the *squares*, and the powers being proportional to the *cubes* of the quantities of air circulated in a given time.

In the parallel imaginary case here taken for illustration, had the steam jet been applied in addition to the natural ventilation, in the absence of furnace action, the motive columns (proportional) would have been 9 for natural ventilating cclumn and 16 for the steam jets, giving a total of 25, and the ventilation would have been 40,000 cubic feet per minute; and, in this condition, the application of the furnace in addition would only have increased the head or height of motive column from 25 up to 50, and thereby appear to have added only 10,000 cubic feet per minute to the quantity of air circulated: thus, on the erroneous principle of comparison adopted in the papers mentioned, the furnace would under such circumstances only appear to have added 10,000 cubic feet per minute to the 40,000 produced by natural causes and the steam jet combined; and hence the furnace itself would, under this improper view, have appeared to have been no more efficient than the steam jet is made to appear in some of the papers already alluded to.

d. Machinery, or Mechanical Ventilation.

Several mechanical means of forcing air into and through mines, commencing with pressures above that of the atmosphere, and terminating at the exit with the necessary velocity due to its area, under the pressure of the outer atmosphere, have been contrived; and in many instances they have been adopted in this country, since the former edition of this work was published: with several kinds of such contrivances there is a very considerable saving of fuel as compared with furnace action, and particularly in shallow pits. On the Continent, and more particularly in Belgium, where the furnace is forbidden by law in fire-damp collieries, they are very generally applied to colliery ventilation.

In the first report by Mr. Buddle to the Society for Preventing Accidents in Coal Mines, before alluded to, mention is made of an air pump, which consists as follows (plate 62, fig. 3) :—*a, a, a, a,* is the body of the pump, which is square; *b* its piston; *c,* its suction pipe, which communicates by the drift *d, d,* with the upcast *e*; *f,* a valve or trap-door; *g, g,* the intake valves; and *h, h,* the discharging valves.

The pump may be worked by a steam engine or other machine attached to the piston rod, *k.* It is made of 3-inch fir plank; the piston is 5 feet square; the stroke 8 feet long; and the suction pipes and valves about one-third of the area of the piston. The piston may work with ease 20 strokes per minute, and will draw 8,000 cubic feet of air in that time; but allowing one-fourth deficiency for the inaccuracy of the piston, valves, &c., it will exhaust 6,000 cubic feet of air per minute. Its power may be increased at pleasure. The power required to work the machine at any given speed will of course depend on the condition and length of the air courses, as already explained.

A defect in the performance of the above apparatus is remedied in another form of air pump, invented by Mr. John Taylor, of Tavistock, and is thus described in Brewster's Edinburgh Encyclopædia.

It is represented in plate 62, fig. 4: *a* is a large cistern, nearly filled with water, made of wooden staves, hooped with iron, circular, and from 6 to 8 feet in depth. Through the bottom of this vessel a pipe, *b*, passes from the mine to be ventilated and upwards through the water, about a foot above it. Upon the top of this pipe is an airtight valve opening upwards: over this pipe and within the sides of the cistern, a cylinder of plate iron is placed, open at the bottom, but close at the top, in which top an airtight valve is placed, also opening upwards. This iron cylinder is made to move in a vertical direction by girders or sliders, and its upper end is attached to a lever or a chain, which is moved either by a water wheel or steam engine. An exhausting machine of this construction may be made from the smallest size, to be worked by the hand, to any requisite size to be moved by machinery (vol. 14, 1820).

The outer casing and four sets of valves of the former machine, with the airometer working in water, substituted for a piston, as seen in the latter, constitute the basis of the machine of Mr. Struvé. (Plate 62, fig. 5.)

According to a statement made by Mr. Wood, at a meeting of the North of England Institute of Mining Engineers, on June 3rd, 1853, a machine of Mr. Struvé's, having an airometer 17 feet in diameter, and worked at from 7½ to 8 strokes per minute by a steam engine of 14 horse-power, produced a ventilation of 22,000 cubic feet per minute, being 22-25ths of its calculated effect: equal to 88 per cent.

A ventilating machine (Struvé's) at Risca, having two airometers 18 feet in diameter each, with a stroke of 6 feet, has produced the following results:—

	CALCULATED EFFECT. Cubic ft. per min.	ACTUAL EFFECT. Cubic ft. per min.	PROPORTION PER CENT.
7 strokes per minute	42,750	30,690	71·8
8 ,, ,,	48,858	37,500	76·7
9 ,, ,,	54,965	41,321	75·2

The difference being due to the leakage of the valves and to a larger volume of return than of fresh air: the latter being that which was measured, and the former that which passed through the machine.

In addition to the above may be mentioned the horizontal piston machine, which has an analogy to that described by Mr. Buddle, and already referred to. A large machine upon this plan has been erected by Mr. Nixon, at Navigation Colliery, near Aberdare: the Elsecar fan, the invention of Mr. Biram: the centrifugal ventilators of Mr. W. Brunton, Mr. Rammell, and Mr. Waddle: the pneumatic screw of M. Motte: the windmill ventilator of M. Lesoinne; the spiral ventilator of M. Pasquet; the inclined vane fan of M. Letoret; the curved vane fan of M. Combes; the pneumatic wheels of M. Fabry, &c.; the chief of which are minutely described and illustrated in Mr. Mackworth's evidence contained in the first report from the Select Committee of the House of Commons on accidents in coal mines in 1853.

Of the two machines, drawings of which are given in plate 63, more than a mere passing notice is necessary. The first of these (figure 1) is a side elevation of the centrifugal ventilating fan of M. Guibal, of Mons, in Belgium. It has been described at

length, as well as illustrated, in a paper by Mr. W. Cochrane, read before the North of England Institute of Mining Engineers, in 1865. (See vol. 14, page 73.)

This ventilator is upon the principle of an exhausting fan. It consists of 8 vanes, each of which is formed of $1\frac{1}{4}$ inch oak cleading, secured to the arms, which are bolted to two octagonal iron bosses keyed on the main shaft. Interlaced as these arms are with each other, they form a very firm structure, and admit in consequence of being driven at a high rate of speed, admitting of a speed of from one hundred and fifty to two hundred revolutions per minute without danger.

A wall is built on each side of the fan, giving about 1 inch clearance to the side of the vanes. Outside of one wall the engine is fixed which drives the fan, and in the other an inlet of proper size is left, such inlet being connected with the upcast shaft. An arch is carried over the fan, giving about 2 inches clearance to the vanes, and in continuation of this arch, an invert to a point about one-eighth of the circumference below the centre line, at which point the 2 inch clearance is increased, gradually expanding the lower curve of the casing till it ends in the sloping side of the chimney formed between the continuation of the side walls of the building, as shown in the figure.

A sliding shutter is fitted into cast iron grooved rails for about one-fifth of the circumference, which enables the concentric circle of the top arch to be completed nearly round the fan—that is, giving the 2 inch clearance to the vanes. The shutter and chimney are claimed by M. Guibal as essential requirements of a perfect ventilating machine. By means of the shutter enlarging or diminishing the outlet, the volume of air drawn by the fan can be so regulated as to suit the special requirements of the mine on which the ventilator is placed, and produce the greatest economical effect; hence the necessity of experimental trials to determine, for each particular mine, the best size of the outlet.

Calling the lowest position of the shutter zero and the highest 1, the position of $\frac{7}{8}$ was fixed as the best at Elswick Colliery, where Mr. Cochrane conducted his experiments.

The following table is an extract from the results :—

No. of Experiment.	Strokes of Engine and Ventilating Fan per Minute.	Position of Shutter.	Indicated Horse Power Applied.	Indicated Horse Power Transmitted to the Fan.	Cubic Feet of Air per Minute.	Water Gauge near Fan at Top of Pit, in Inches.	Calculated Useful Effect in Horse Power.	Calculated per Cent. of Useful Effect on the Whole Power Applied.	Calculated per Cent. of Useful Effect on Power Transmitted to Fan.
1	20	1	2·59	1·99	24·123	·200	·76	29·34	38·2
2	38	1	9·94	8·37	38·487	·600	3·64	36·62	43·5
3	38	$\frac{3}{4}$	10·02	8·81	39·883	·550	3·45	34·43	39·1
4	39	$\frac{1}{2}$	9·72	7·80	36·504	·500	2·88	29·63	37·0
5	39	$\frac{1}{4}$	8·21	6·85	29·641	·250	1·17	14·26	17·1
6	41	0	7·63	6·00	23·469	·100	·37	4·85	6·2
7	55	1	23·84	20·94	56·378	1·200	10·66	44·71	50·9
8	55	...	...	...	56·995	...	...	...	...
9	$57\frac{1}{4}$	1	23·53	19·73	60·441	1·400	13·33	52·40	67·56
10	87	1	69·96	58·16	85·544	2·550	34·37	49·13	59·10
11	94	1	...	not indicated	104·943	3·150	52·09	...	...

In this case the outside diameter of the vanes was 23 feet; the width 6 feet $6\frac{3}{4}$ inches, and each vane extended about 8 feet into the interior of the fan. The cost of a similar fan and engine was about £400 manufactured in Belgium, including patent royalty; and the additional cost of erection (bricks costing 25 shillings per thousand) was £240, including a connecting drift to the upcast.

The Brunton, Rammell, and Waddle fans have the good properties of being simple, open, and perhaps more accessible than that of M. Guibal, for observation, repairs, &c.; but on the other hand, there is reason to think that the fuel consumed by them is about one-fourth greater in amount for a given amount of power utilised in the production of ventilation than it is in the fans of M. Guibal.

The only other ventilating machine which we shall particularise is the feathering fan of M. Lemielle (plate 63, fig. 2).

The construction of the machine will be understood by referring to the plan, which is sectional: it is placed in a chamber of masonry, which communicates on one side with the upcast shaft, and on the opposite side within the external atmosphere. Within this chamber there revolves a drum, which is placed eccentrically in the chamber: at equal distances three vertical shutters are hinged to the drum, the outer edges of the shutters being kept close to the walls of the chamber by the rods which radiate from, and revolve at their centres upon the fixed shaft.

The outer edges of the shutters should fit the interior of the chamber as nearly as possible, but in practice some leakage always takes place.

The following extract, illustrative of the performance of a Lemielle Ventilating Machine at Page Bank Colliery, near Durham, is made from a paper read by Mr. William Steavenson to the North of England Institute of Mining Engineers in 1869, (vol. 18, page 69) :—

NO. OF EXPERIMENT.	STROKES OF ENGINE AND VENTILATING MACHINE PER MINUTE.	INDICATED HORSE POWER APPLIED.	CUBIC FEET OF AIR PER MINUTE.	WATER GAUGE IN INCHES.	CALCULATED PER CENT. OF USEFUL EFFECT ON THE WHOLE POWER APPLIED.
1	8·60	50·203	56,621	1·83	32·522
2	10·00	56·240	60,757	2·50	42·550
3	10·10	80·931	60,312	2·65	31·117
4	10·00	73·080	59,166	2·65	33·800
5	11·95	127·574	75,962	3·35	31·431
6	14·50	207·265	98,165	5·20	38·808
7	16·00	266·283	97,338	6·65	38·333

Prior to the application of the fan at Page Bank Colliery, furnace ventilation was employed, and the results of the two modes are given in Mr. Steavenson's paper.

"The furnace yielded, when at its best, 39,997 cubic feet under 0·90 in. water guage, and to prove the accuracy of this, if we compare it with our first fan experiment we get the theoretical duty of the furnace.

$$39{,}997 \text{ cubic feet} \sqrt{\frac{1{\cdot}83}{{\cdot}90}} = 57{,}195 \text{ cubic feet.}$$

The fan gives at 1·83 water gauge 56,621, which is as nearly as possible correct.

The furnace was then consuming 41·10 lbs. of coal per horse power per hour. As soon as engine power is applied this is reduced to the usual standard of 12 lbs. per horse power applied, and in the case of a fan utilizing 45 per cent. this becomes 26 lbs., or 36 per cent. less coals with the fan than with the furnace—this, upon the quantity of air now passing through the mine, amounts to a saving in coals and wages of £448 per annum, assuming that the furnace could have done the work, but it could not do more than it was doing; whereas we have now nearly doubled the air, and have a good margin in hand for future requirements."

These observations seem scarcely in accordance with the tabular statement previously given. The experiment which is adduced in order to compare the fan with the furnace, shows a utilization of only 32·522 per cent. of the engine power, and not of 45 per cent.: the consumption of coal would, therefore, become 37 lbs. per horse power per hour as compared with 41·10 lbs. consumed by the furnace, being a saving of not more than 10, instead of 36 per cent., as stated.

Why anything like 12 lbs. per horse power per hour should be used by the engine requires explanation. If this were brought down to the right standard of 3 or 3½ lbs. per horse power per hour, the economy, as regards fuel, of ventilation by machinery would be very apparent.

In testing the relative proportions of useful effect produced by different ventilations, it is necessary to recollect that the water gauge at the top of the upcast shaft connected with a fan or pump near to it, indicates the *total* difference of barometrical pressure between the outer atmosphere and the air within the circuit of ventilation: and (except under extreme and unusual conditions) without any appreciable error we may consider water to weigh 62·4 lbs. avoirdupois per cubic foot: so that each inch of water column or gauge represents $\frac{62{\cdot}4}{12} = 5{\cdot}2$ lbs. per square foot of ventilating pressure: and in order to ascertain the actual power developed in the production of ventilation, we have only to multiply in such cases the difference in inches of the level of the water as indicated by the water gauge by 5·2 to find the pounds pressure per square foot; and this, multiplied by the number of cubic feet of air circulated per minute, gives the foot pounds of developed power per minute, and this product divided by 33,000 gives the horse-power utilized.

If, at the time when the quantity of air is measured and the water gauge read off, there is an indication of the engine taken, we have the necessary data for determining the proportion or per centage of the engine power that is really utilised.

With the water gauge underground the case is not the same, the reading of the instrument in such cases not including the indication of the resistances that the air meets with in the shafts; and the consumption of coal per horse-power per hour, in the

production of the furnace ventilation, as stated above, is therefore in all probability somewhat over-rated.

All machine ventilators are liable to one very serious objection—their liability to derangement, and the consequently unventilated state of the mine until they can be repaired. The heat of the upcast shaft of a mine ventilated by furnace is such as to cause a considerable circulation of air for many hours after it has been extinguished; and a proper arrangement with regard to dumb drifts for currents which might chance to be dangerously loaded with explosive gas, will always preclude the slightest risk arising from their passing in too close proximity to the fire.

That air, put in motion, has momentum in common with other bodies, no one will doubt; but that its momentum in mines is almost instantaneously overcome by the friction or resistance of the air channels is equally true. In proof of this may be stated a fact, elicited during the application of the exhaust steam from an underground steam engine to ventilate Belmont Colliery, when each stroke of the engine was distinctly observable in the workings by its effect upon the doors; and in describing the ventilation by Mr. Struvé's machine (before alluded to), Mr. Wood stated that the pulsation of each stroke of airometer piston was distinctly felt in the workings at a considerable distance from the shaft.

CHAPTER VIII.

THE LIGHTING OF MINES—CANDLES—OIL LAMPS—GAS—STEEL MILLS—SAFETY LAMPS.

In the working of mines, where we do not find any fire-damp, we may use throughout the whole of the excavations any species of illuminating power we please, the most usual being the tallow candle or oil lamp.

In the Newcastle district the candle is chiefly used, except near the shafts, where more light is requisite, and where in consequence oil lamps or gas lights are substituted.

The pit candle is commonly of small size, weighing from 30 to 50 to the pound: it ought to be made of clean ox tallow, with the wick small and of fine cotton.

In the Scotch collieries, small oil lamps are used, which are carried about by being stuck in the front of the miners' caps.

When gas is used, it may be either manufactured underground, or conveyed down the shaft from a gasometer at the surface. When made underground, the heat from the fires beneath the retorts may be economically applied to aid the ventilation of the mine.

The repeated accidents caused by the explosion of fire-damp in fiery mines, rendered desirable some method of lighting them by an agency incapable of communicating combustion to the surrounding atmosphere.

The first light used in foul places was supplied by the steel mill, which consists of a brass wheel about 5 inches in diameter, with fifty-two teeth, working a pinion with eleven teeth: on the axle of the latter is fixed a thin steel wheel, from 5 to 6 inches in diameter. The wheels are placed in a light frame of iron, which is suspended by a leather belt round the neck of the person who plays the mill. Great velocity is given to the steel wheel by turning the handle of the toothed wheel; and the sharp edge of a flint, applied to the circumference of the steel wheel, immediately elicits an abundance of sparks, and emits considerable light.

When elicited in atmospheric air, they are of a bright appearance, rather inclining to a reddish hue, and as they fly off the wheel seem sharp and pointed. In a current of air mixed with inflammable gas, above the firing point with candles, they increase considerably in size, and become more luminous. If played in an atmosphere consisting of freshly discharged gas, and pure atmospheric air in explosive proportions, the sparks become still more luminous, assume a liquid appearance, and speedily

produce an explosion. When the inflammable gas predominates in the circulating current, the sparks become of a blood red colour, and, as the proportion increases, the mill ceases to elicit sparks altogether. The mill gives also blood red sparks in carbonic acid.

In addition, however, to its want of security under certain circumstances, the light afforded by the steel mill was at best only an indifferent one, and, as it required the constant employment of a strong lad to work it, was very expensive.

The first safety lamp was invented by the late Dr. William Reid Clanny, of Sunderland, in the year 1813, and tried in the Harrington Mill pit, in the county of Durham, in an inflammable atmosphere, November 20th, 1815. In this lamp the flame was insulated, and supplied with the air necessary for its support by a pair of bellows, the separating medium between the internal and external air being the water through which the air was passed. This lamp was, however, very cumbrous, and was soon superseded by the elegant inventions of the late Mr. George Stephenson and Sir Humphrey Davy.

In the latter part of the year 1815, Mr. Stephenson, then an engineer at Killingworth Colliery, directed his attention to the subject, the result of which was his contrivance of a safety lamp, and the process by which he arrived at such a result is explained by himself, as follows :—

> "About the month of August, 1815, I was in the habit of making experiments upon blowers, and found that when they were lighted, and a number of lighted candles—namely, four, five, or six, held to the windward of the lighted blowers, the blowers were put out by the burnt air, which was carried towards them. *Hence I conceived that if a lamp could be made to contain the burnt air above the flame, and to permit the fire-damp to come in below in a small quantity, to be burnt as it came in, the burnt air would prevent the passing of explosion upwards, and the velocity of the current would also prevent its passing downwards.*"

Without detailing the various experiments by which Mr. Stephenson arrived at the production of his lamp, it may be simply stated that it is in principle (discarding the wire gauze by which it is now surrounded, as a protection to the glass) as safe as any lamp depending on that portion of it made of glass remaining entire. (Plate 64, figure 1.)

Sir Humphrey Davy, in 1815 (about the same time with Mr. Stephenson), after having tried without success Kunckel's, Canton's, and Baldwin's phosphorus, and likewise the electrical light, proceeds in his Treatise on the Safety Lamp to give the details of the various processes and reasonings by which he eventually arrived at the construction of "the Davy," a lamp which for simplicity and safety, under proper management, is still unsurpassed, and which affords a fine illustration of the great advantage to be derived by practice from the aid of science. (Plate 64, figure 2) :—

> "In exploding a mixture in a glass tube of one-fourth of an inch in diameter, and a foot long, more than a second was required before the flame reached from one end to the other; and I found that in tubes of one-seventh of an inch in diameter explosive mixtures could not be fired when

they were opened in the atmosphere, and that metallic tubes prevented explosion better than glass tubes. I first tried the effect of lamps in which there was a very limited circulation of air, and I found that when a taper in a close lantern was supplied with air so as to burn feebly, from very small apertures below the flame, and at a considerable distance from it, it became extinguished in explosive mixtures, but I ascertained that precautions, which it would be dangerous to trust to workmen, were required to make this form of lamp safe, and that at best it would give only a feeble light; and I immediately adopted systems of tubes, above and below, of that diameter in which I had ascertained that explosions would not take place. In this mode of experimenting I soon discovered that a few apertures, even of very small diameter, were not safe unless their sides were very deep; that a single tube of 1-28th of an inch in diameter, and two inches long, suffered the explosion to pass through it; and that a great number of small tubes, or of apertures, stopped explosion, even when the depths of their sides were only equal to their diameters: and at last I arrived at the conclusion that a metallic tissue, however fine and thin, of which the apertures filled more space than the cooling surface, so as to be permeable to air and light, offered a perfect barrier to explosion, from the force being divided between, and the heat communicated to, an immense number of surfaces.

"My first safety lamps, constructed on these principles, gave light in explosive mixtures containing a great excess of air, but became extinguished in explosive mixtures in which the fire-damp was in sufficient quantity to absorb the whole of the oxygen of the air, so that such mixtures never burnt continuously as the air feeders, which in lamps of this construction was important, as the increase of heat where there was only a small cooling surface would have altered the conditions of security. I made several attempts to construct safety lamps which should give light in all explosive mixtures of fire-damp, and, after complicated combinations, I at length arrived at one evidently the most simple, that of surrounding the light entirely by wire gauze, and making the same tissue feed the flame with air, and remit light.

"In plunging a light surrounded by a cylinder of fine wire gauze into an explosive mixture, I saw the whole cylinder become quietly and gradually filled with flame; the upper part of it soon appeared red hot, yet no explosion was produced. It was easy at once to see that by increasing the cooling surface at the top, or in any other part of the lamp, the heat acquired by it might be diminished to any extent; and I immediately made a number of experiments to perfect this invention, which was evidently the one to be adopted, *as it excluded the necessity of using glass, or any fusible or brittle substance, in the lamp*, and not only deprived the fire-damp of its explosive powers, but rendered it a useful light.

"I found that iron gauze, composed of 1-40th to 1-60th of an inch in diameter, and containing 28 wires or 784 apertures to the inch, was safe under all circumstances in atmospheres of this kind; and I consequently adopted this material in guarding lamps for the coal mines, where, in January, 1816, they were immediately adopted, and have long been in general use."

Every Davy, to be safe, should of course be in a perfect state: it should always be securely locked when in use, and furnished with a shield, which, in order to combine the necessary protection from currents of gas, by which the lamp is liable to be assailed in every direction, with the requisite transmission of light, should be made of glass or other transparent substance, and extend from the bottom to the top of the lamp, proper arrangements being made for the entrance of the air for the support of combustion.

Since the application of wire gauze by Sir Humphrey Davy, many lamps have

been constructed, some of which display great ingenuity, the principal object of which may be stated as being the attempt to combine the safety cf the Davy with the illuminating power of the candle.

There can at this day, I think, exist in unprejudiced minds no doubt that this improvement on the Davy, if such it can be called, was arrived at by Mr. Stephenson; and the application of glass was condemned by Sir Humphrey Davy himself.

Among the glass lamps may be mentioned the following:—

1. The CLANNY lamp, which consists of a lower cylinder of stout glass surrounding the flame, and an upper cylinder of wire gauze of less diameter. In this lamp, the air to feed the lamp passes through the lower part of the wire gauze cylinder, down the inside of the glass cylinder, the burnt air ascending inside of the cold air current, and escaping through the meshes of the upper part of the wire gauze; this, then, is a lamp protected by a single glass. This lamp with a short cone or cylinder of safety gauze which reaches to a little below the top of the glass cylinder, and surrounding the flame, is perfectly safe. (Transactions of the North of England Institute of Mining Engineers, vol. 17, page 37.)

2. The MUESELER lamp is extensively used in Belgium, and does not differ much from the Clanny; but in this lamp there is a copper chimney to carry off the smoke from the wick of the burner, the air being admitted through the gauze at the top.

3. The BOTY lamp is another modification of this principle, having a glass cylinder with a wire gauze top; but in this the air is admitted through a ring of perforated copper at the bottom of the lamp. In other respects, it does not differ much from the Mueseler lamp.

4. The ELOIN lamp has also a glass cylinder, the air is admitted through wire gauze near the bottom of the lamp, and is thrown against the burner by a thin copper cap. No other air enters the lamp than at the bottom through the gauze, and the space for admission of air being small, it is in consequence easily extinguished. Instead of having a cylinder of gauze for the top, this lamp has a copper or brass top, the exit for the vitiated air being at the top through the wire gauze. This lamp has an argand burner, or flat wick; it gives a good light, but the top of the lamp soon becomes excessively hot.

5. The lamp patented by the late Dr. R. M. Glover and Mr. J. Cail, of Newcastle-upon-Tyne, has a double glass cylinder, the air being admitted from the top through wire gauze between the two cylinders, and, passing downwards, enters within the inner cylinder at the bottom of the lamp through a second wire gauze, by which it passes to the burner. The two cylinders are for protection in case of accident; and the air passed between the cylinders, operates in keeping the external cylinder cool, and thus removing its liability to crack on exposure to a drop of cold water. The top of the lamp is wire gauze. This lamp, like the Mueseler, has also a chimney by which, as stated in the specification of the patentees, "currents of air are prevented from

affecting the steadiness of the light." This lamp (plate 64, figure 3), although a little complex, I consider to be one of the best of those dependent on glass for their safety; and, as a surveying lamp, placed in careful hands, I have no hesitation in pronouncing it one of the best lamps which has yet appeared.

As a combination of the safety principle of the wire gauze, the equable currents produced by the double glasses, the brilliant light of the argand burner, with perfect portability, may be mentioned the elegant lamp of the late Mr. T. Y. Hall, of Newcastle-upon-Tyne.

This lamp (plate 64, figure 4), without presenting (if we may except, as mentioned by Mr. Hall, the cylinder of glass within the gauze, resting upon the dome of the air vault, and closely surrounding the central aperture) any very original features, is chiefly pre-eminent for the beautiful arrangement of its details; and, possessing, as it does, the complete protection of the wire gauze, it may be placed in any hands, and may be mentioned as a perfectly safe lamp, when in proper order. To it, however, there is an objection, on account of the number of its parts and the complication of their arrangement, an objection of no inconsiderable importance when we consider the number of persons in whose hands lamps are placed, and the certainty that there will always be some who will not give them that care and attention without which they are worse than useless.

Proposals have been made to light mines by reflected light. This plan, however, could not probably be found practicable, on account of the obstructions which are continually occurring in the passages.

CHAPTER IX.

ACCIDENTS IN MINES.

The chief causes of accidents in mines are explosions of fire-damp, inundations, and falls of stone. There are also accidents arising from the breakages of ropes and chains, and from the derangement of machinery.

Explosions may arise from any of the following causes :—

In working in the whole mine, candles being commonly in use, the air in consequence of bad ventilation, may be gradually loaded with fire-damp to the firing point, in which case we will have a thorough blast, but this is a rare occurrence.

We may have a good ventilation, but a sudden outburst of gas from a blower may rapidly raise it to the firing point. This I believe to have been the cause of many explosions.

The ventilation may wholly cease, from the neglect of doors or injury of stoppings. In this case a district might soon be filled with inflammable air, which would probably result in explosion.

An accident happening to a safety lamp where gas is present may also cause an explosion.

And as before stated, a good ventilation, mismanaged so as to cause the pressure of the air currents to be from the pillar or lamp districts into these worked with candles, may also be attended with fatal results.

The question is—are any or all of these causes of accident controlable, and to what extent ?

There is, under ordinary circumstances, no excuse for any accident from deficiency of air ; because it is quite sufficiently established that a quantity sufficient to meet all ordinary cases may be easily caused to circulate through the workings of a mine, the only requisites being a powerful furnace, or the application of some other artificial means of producing ventilation, and, what are of the highest importance, spacious airways.

I believe that, notwithstanding the great quantity of air which we find in many of the collieries of the North of England and elsewhere, a large addition could be made to it by a due attention in this respect. We cannot reduce the resistance in the shafts, &c., so as to make the practical come anywhere near the theoretical velocity ; but there is a great margin for the acquirement of an increased quantity through the workings, which is very evident from the construction of the formulæ

relating to the comparison between theoretical and practical velocities. We should always have, if possible, two returns from each district; or, if we cannot effect this, have the single air course continually inspected, so as to preclude the possibility of its becoming at any time contracted and insufficient.

It ought also, generally speaking, to be made a rule to have no timber supports in the return airways, because they are very liable to decay, and, by becoming unable to support the pressure, to break, and allow the roof to fall and block up the air course. The airways ought, therefore, to be supported by stone pillarings at their sides, which may be constructed of the stone which falls from the roof when the timber props are withdrawn.

As regards the liability to explosion from blowers or "bags of gas," no amount of ventilation can prevent it; the only safeguard against such accidents consisting in the constant and exclusive use of safety lamps in the whole of the working places and returns, naked lights being confined to the rolleyways. In fact, the probability is, that, the greater the ventilation under such circumstances, the greater will the explosion be, on account of the more rapid and extensive formation of explosive compound.

To the safety lamp, then, alone must we look for the prevention of accidents in mines subject to sudden outbursts of gas, in which list we may include all which are termed fiery mines.

The only method of preventing accidents arising from neglect of doors or injury of stoppings is, to have an active and intelligent superintendence over such matters. There are, or ought to be, in all fiery mines especially, overmen, who, if they cannot immediately detect any deficiency in their air current, are totally unfit for their situations.

An accident may happen to a safety lamp from a fall of stone; and, as far as possible to prevent this, the lamps should be used under strict regulations, printed forms of which should be placed in the hands of the workmen and exposed in conspicuous places about the works.

By far the greatest fatality consequent upon explosions of fire-damp arises from suffocation occasioned by the after-damp.

The following diagram is illustrative of the combustion of fire-damp, of which the product is after-damp, called also choke-damp:—

BEFORE COMBUSTION.	ELEMENTARY MIXTURE.		PRODUCTS OF COMBUSTION.
Weight.	Atoms.	Weight.	Weight.
	1 carbon	6	22 carbonic acid
8 carburetted hydrogen	1 hydrogen	1	9 steam
	1 hydrogen	1	9 steam
	1 oxygen	8	
	1 oxygen	8	
144 atmospheric air.........	1 oxygen	8	
	1 oxygen	8	
	8 nitrogen	112	112 uncombined nitrogen
152		152	152 after-damp

From the above, it appears that choke, or after-damp, consists by weight of 22 parts of carbonic acid, 18 of steam, which is condensed, and 112 of uncombined nitrogen; therefore we may call it more correctly a compound of 22 carbonic acid and 112 nitrogen. The specific gravity of such a gas will, therefore, be 1·066, or so little above that of common air that it may be assumed to form a uniform mixture with it.

The derangement of the air stoppings, resulting generally from an explosion, causes the air to escape from the downcast to the upcast shaft by more direct channels than the workings where the accident has occurred; the consequence of which is, that in most cases, before the ventilation can be restored the unfortunate sufferers have ceased to live.

The modes of operation which appear practically (at least to a great extent) to remedy this evil, consist in having, when such an arrangement can be effected, the downcast and upcast shafts at opposite extremities of the workings, or in having distinct *pairs* of drifts for intakes or returns, these only being communicated together where rendered absolutely necessary; or, which amounts to the same thing, and possesses the advantage of applicability to existing and extended workings, in having the main returns driven in an upper and adjacent seam of coal, when there is such at no great distance from the working seam. All the necessary artificial barriers between intake and return courses should, of course, be of the most substantial description. By such precautions as these the force of a blast, by being more confined, might be more powerful; but this possible disadvantage would be many times overbalanced by their certain value in the facility they would afford to the speedy restoration of the circulation of air.

Inundations may happen from any of the following causes:—

By incautious workings beneath seas or rivers;
By communication with drowned workings;
Or, by the working out of pillars under drowned workings.

With regard to the safety or otherwise of working beneath masses of water, whether the same be at the surface or contained in the workings of an upper seam of coal, this must altogether depend upon the situation, the strength and thickness of the coal, and the nature of the superincumbent strata. There may be no danger in working within twenty fathoms of such waters, leaving proper pillars, the removal of which is, of course, out of the question. In the approach of drowned wastes, borings must always be made, as has been previously explained.

With regard to the other accidents arising from falls of stone, breakages of ropes, &c., or derangement of machinery, they fall, in a great measure, within that category to which we must continue to a greater or less extent liable, in proportion to the number of people employed and the amount of work they perform. There is no doubt that many accidents might have been, by proper precaution, avoided; but when

we reflect that their causes are so numerous, we may well imagine that even by the most careful some circumstances occasioning an accident may have been overlooked.

All that can be done is, for every one in his own department to give the most unwavering attention to his duties, so that if, notwithstanding this, any accident should happen, he may be clear of that most severe of punishments, self-condemnation.

In every colliery where inflammable gas is met with, a barometer ought to be placed at the bottom of the shaft, and a daily register kept by the overman of the height of the mercury. He should also at the same time test, by experiment, the quantity of air passing into the mine. Instead of the ordinary mercurial barometer, a water barometer might be easily constructed in the following manner (see plate 64, figure 5) :—

Let *a* be a cistern placed at the bottom of the shaft, the level of the water in which is kept constantly the same by a stream of water flowing into it, the surplus being carried away by the waste pipe, *b* : *c* is a close-topped metal pipe, 36 feet long and 3½ inches in diameter, which is filled with water, plugged up at the surface, and lowered down into the cistern, the bottom of the pipe being allowed to remain six inches below the surface of the water when the plug is withdrawn. *d* is a hollow ball of thin brass, which, being passed to the bottom of the tube, will ascend to the surface of the water in the tube, and rise and fall with it.

A piece of fine wire cord attached to this ball may be passed round a pulley and conveyed to work the pointer of a dial in the ordinary way. The range of the water, as compared with the mercurial barometer, being so great, would enable atmospheric changes to be much more easily discoverable, and consequently give earlier notice of the approach of danger.

It is necessary in all mines to have accurate plans, upon which the workings should be registered to within a few weeks of their actual condition : by this means accidents arising from communication with old workings full of water or foul air could never occur.

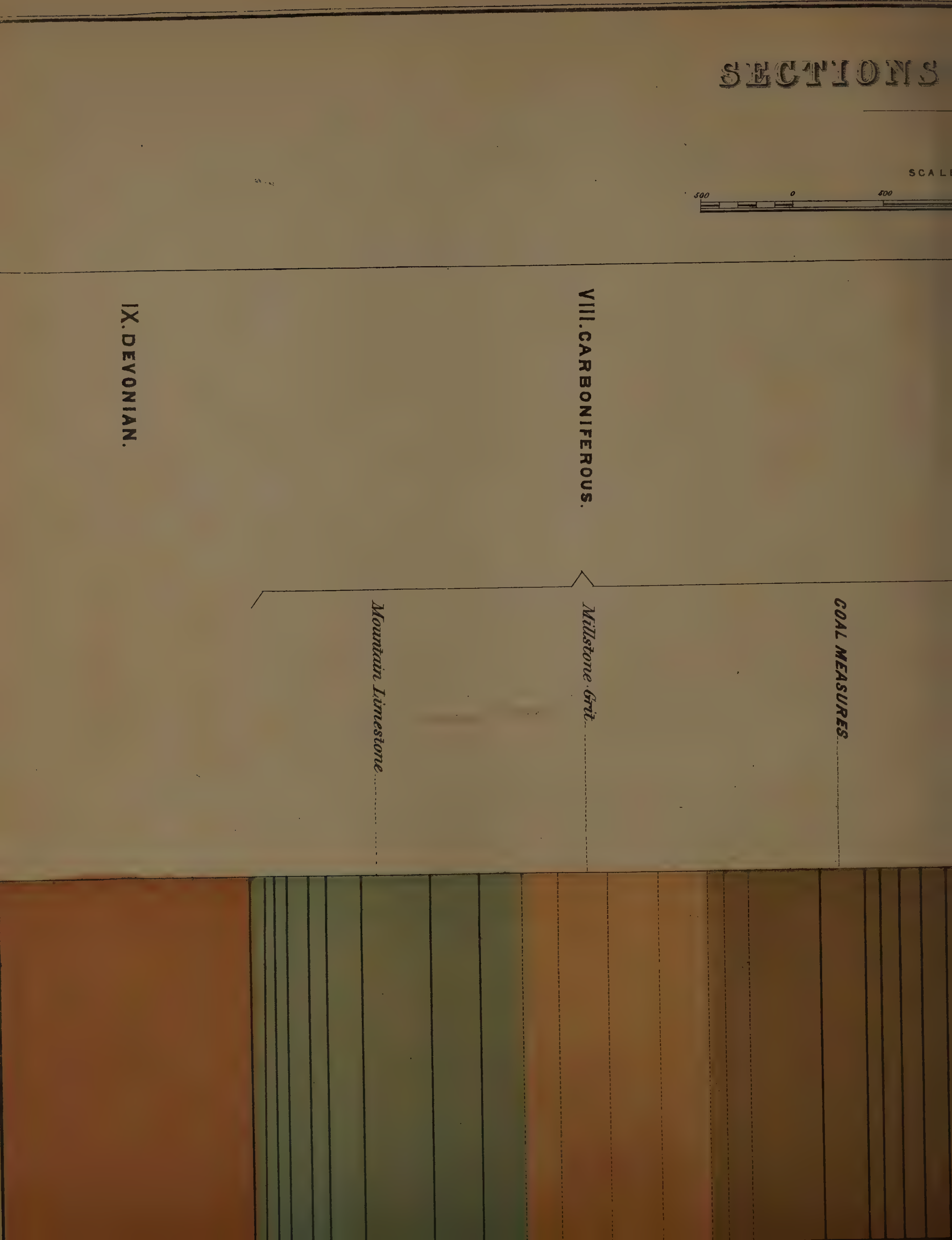
It may be stated, in conclusion, that few accidents need happen if we avail ourselves to the utmost of those appliances of mining now in our possession. The ventilation we are able to establish is sufficient for most cases, if not for all. Casualties of explosion, so long as unprotected lights are used in the working of fiery mines, will inevitably occur. The machinery of mines, in proper order, is safe, so far as the dependence to be placed on the strength and soundness of materials can make it ; and ordinary accidents must be averted by carefulness in the general system pursued in carrying on the working of mines.

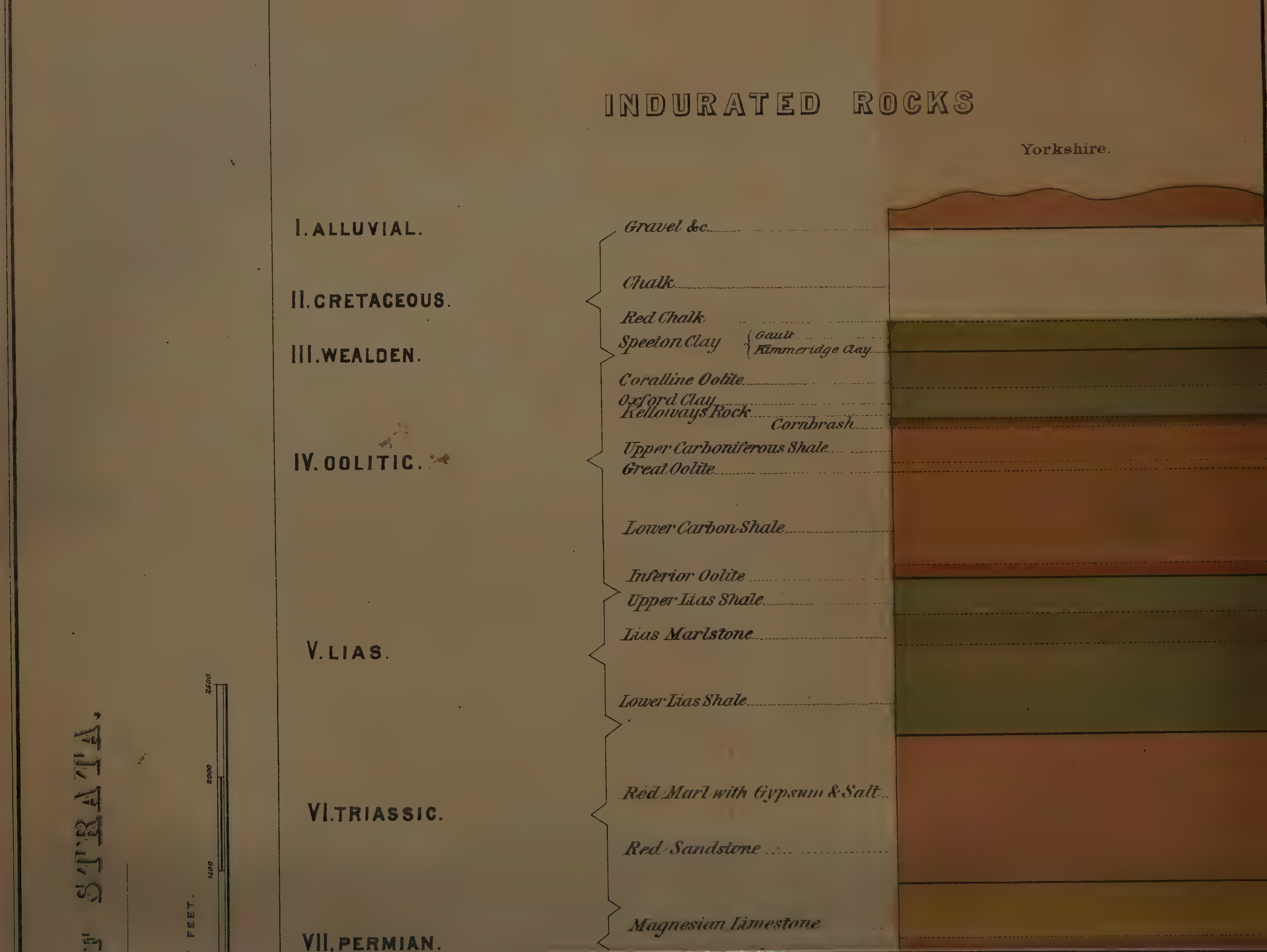
REFERENCE TO THE PLATES.

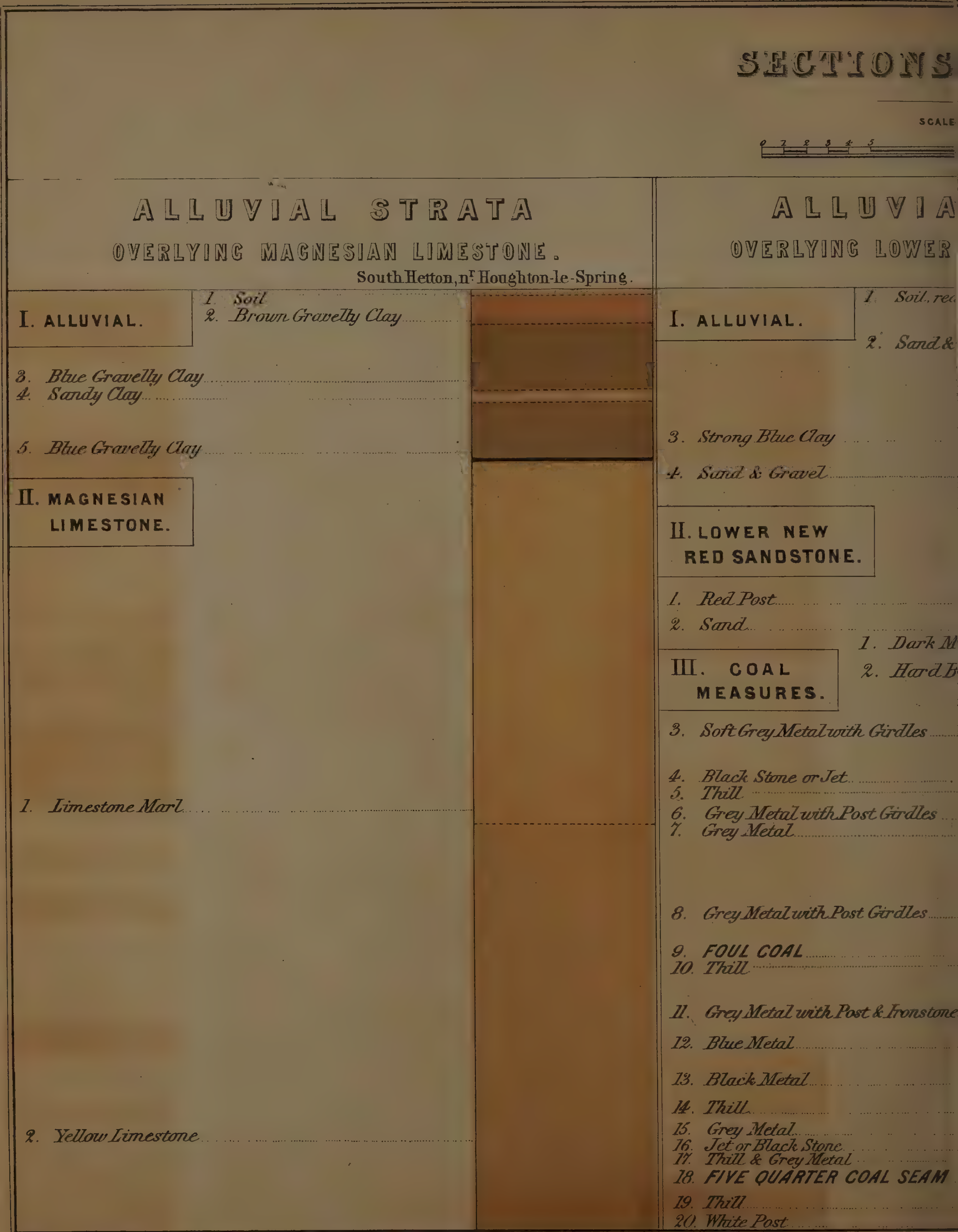
PLATE

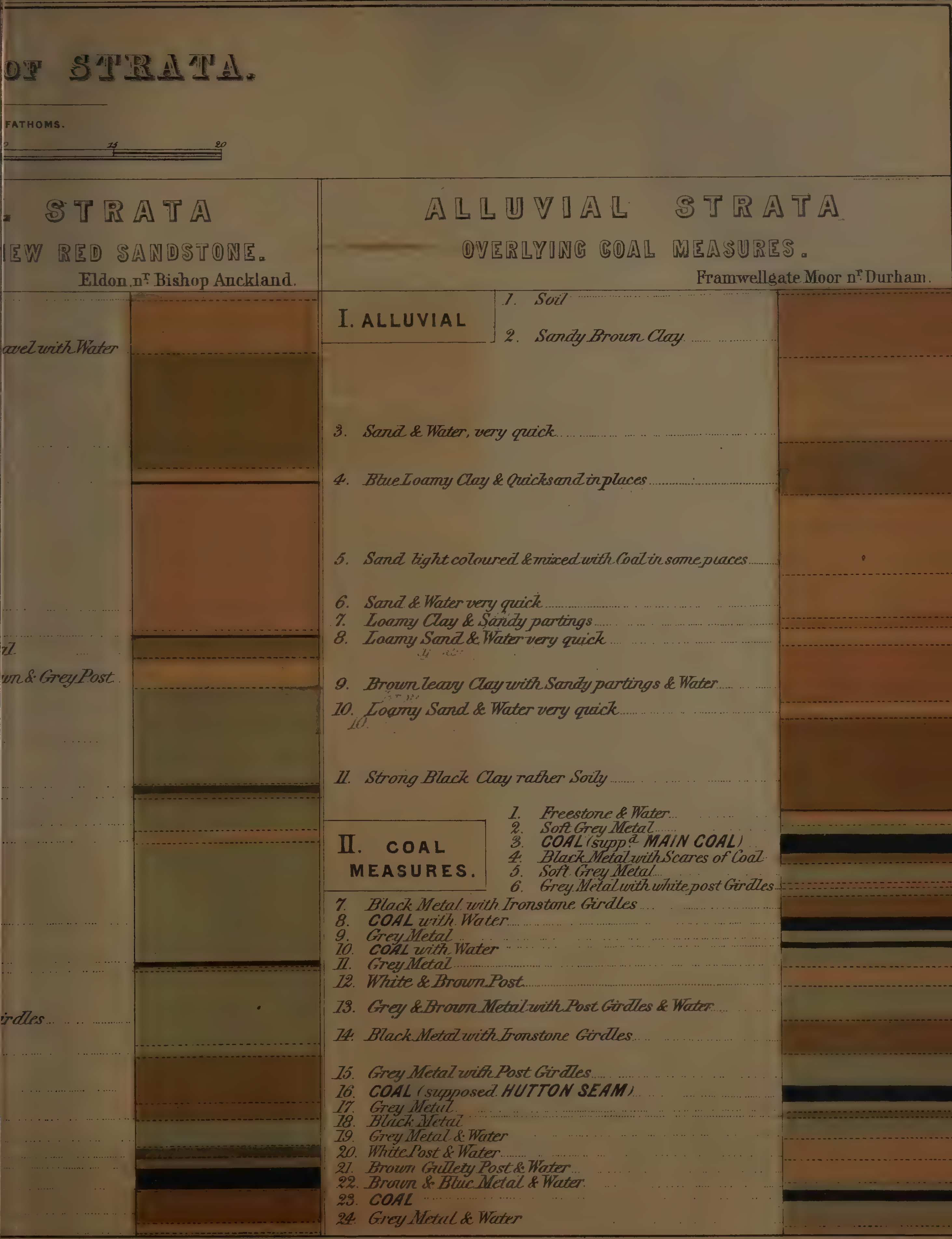
INDEX.

NEWCASTLE-UPON-TYNE: PRINTED BY M. AND M. W. LAMBERT, GREY STREET.


SECTIONS
SCALE
500
0
500
IX. DEVONIAN.
VIII. CARBONIFEROUS.
Mountain Limestone
Millstone Grit
COAL MEASURES


STRATA.
FEET.
1600
2000
2500
INDURATED ROCKS
Yorkshire.
I. ALLUVIAL.
II. CRETACEOUS.
III. WEALDEN.
IV. OOLITIC.
V. LIAS.
VI. TRIASSIC.
VII. PERMIAN.
Gravel &c.
Chalk
Red Chalk
Speeton Clay
Gault
Kimmeridge Clay
Coralline Oolite
Oxford Clay
Kelloways Rock
Cornbrash
Upper Carboniferous Shale
Great Oolite
Lower Carbon Shale
Inferior Oolite
Upper Lias Shale
Lias Marlstone
Lower Lias Shale
Red Marl with Gypsum & Salt
Red Sandstone
Magnesian Limestone


SECTIONS
SCALE
0 1 2 3 4 5
ALLUVIAL STRATA
OVERLYING MAGNESIAN LIMESTONE.
South Hetton, nr Houghton-le-Spring.
I. ALLUVIAL.
1. Soil
2. Brown Gravelly Clay
3. Blue Gravelly Clay
4. Sandy Clay
5. Blue Gravelly Clay
II. MAGNESIAN LIMESTONE.
1. Limestone Marl
2. Yellow Limestone
ALLUVIA
OVERLYING LOWER
I. ALLUVIAL.
1. Soil, re
2. Sand &
3. Strong Blue Clay
4. Sand & Gravel
II. LOWER NEW RED SANDSTONE.
1. Red Post
2. Sand
III. COAL MEASURES.
1. Dark M
2. Hard B
3. Soft Grey Metal with Girdles
4. Black Stone or Jet
5. Thill
6. Grey Metal with Post Girdles
7. Grey Metal
8. Grey Metal with Post Girdles
9. FOUL COAL
10. Thill
11. Grey Metal with Post & Ironstone
12. Blue Metal
13. Black Metal
14. Thill
15. Grey Metal
16. Jet or Black Stone
17. Thill & Grey Metal
18. FIVE QUARTER COAL SEAM
19. Thill
20. White Post


OF STRATA.
FATHOMS.
15
20
. STRATA
EW RED SANDSTONE.
Eldon nr. Bishop Auckland.
avel with Water
al
wn & Grey Post
irdles
ALLUVIAL STRATA
OVERLYING COAL MEASURES.
Framwellgate Moor nr. Durham.
I. ALLUVIAL
1. Soil
2. Sandy Brown Clay
3. Sand & Water, very quick
4. Blue Loamy Clay & Quicksand in places
5. Sand light coloured & mixed with Coal in some places
6. Sand & Water very quick
7. Loamy Clay & Sandy partings
8. Loamy Sand & Water very quick
9. Brown leavy Clay with Sandy partings & Water
10. Loamy Sand & Water very quick
11. Strong Black Clay rather Soily
II. COAL MEASURES.
1. Freestone & Water
2. Soft Grey Metal
3. COAL (suppd. MAIN COAL)
4. Black Metal with Scares of Coal
5. Soft Grey Metal
6. Grey Metal with white post Girdles
7. Black Metal with Ironstone Girdles
8. COAL with Water
9. Grey Metal
10. COAL with Water
11. Grey Metal
12. White & Brown Post
13. Grey & Brown Metal with Post Girdles & Water
14. Black Metal with Ironstone Girdles
15. Grey Metal with Post Girdles
16. COAL (supposed HUTTON SEAM)
17. Grey Metal
18. Black Metal
19. Grey Metal & Water
20. White Post & Water
21. Brown Gullety Post & Water
22. Brown & Blue Metal & Water
23. COAL
24. Grey Metal & Water
Lambert's Lith. Newcastle

SECTIONS

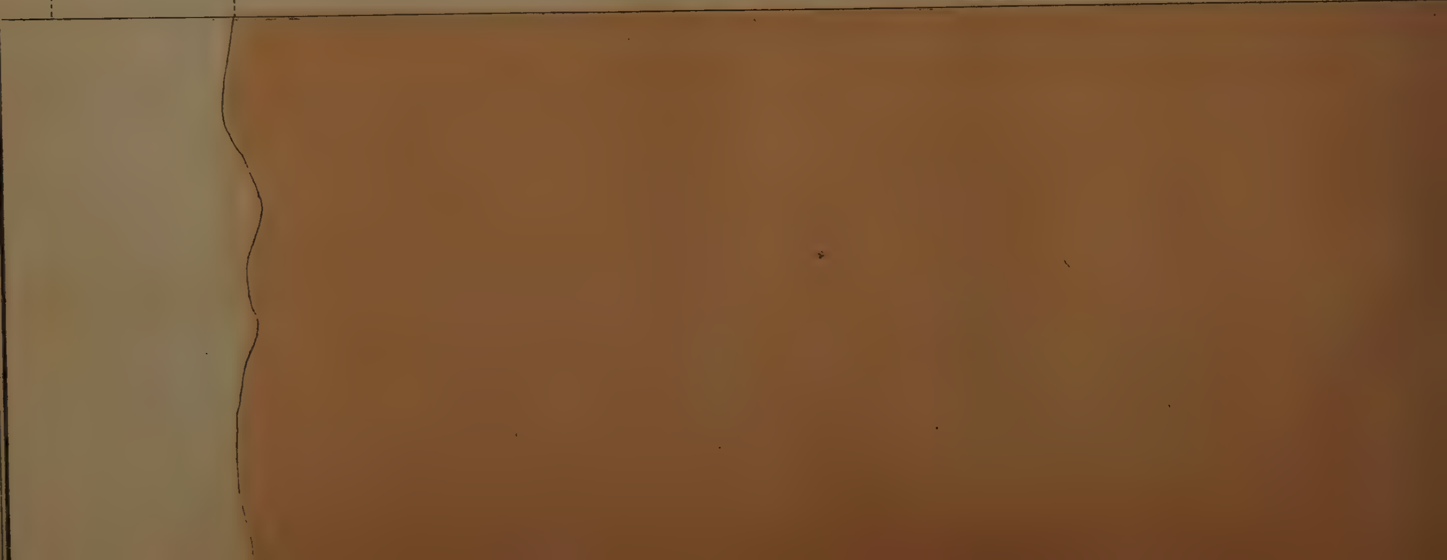
SCALE

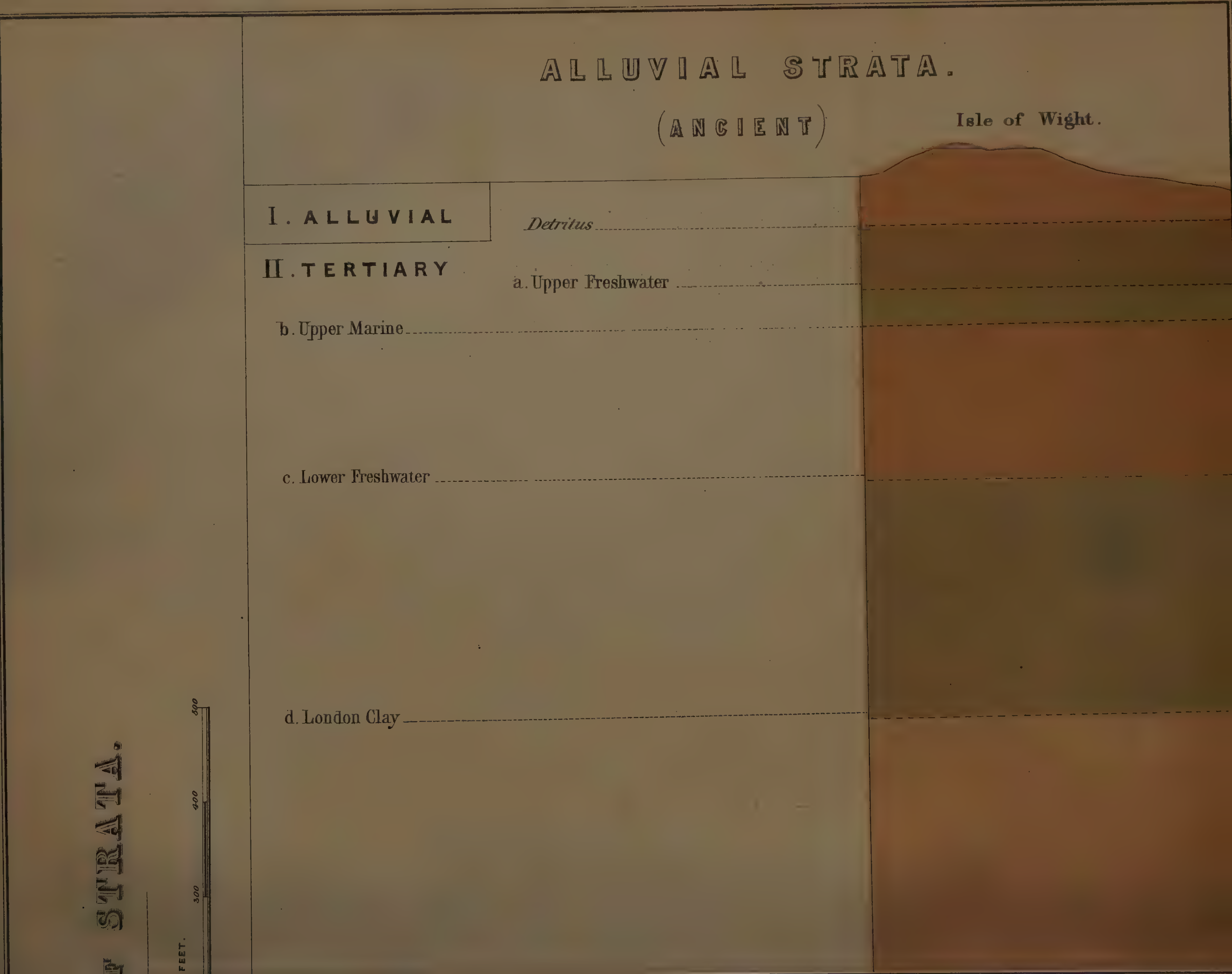
100 50 0 100

e. Plastic Clay

III. CRETACEOUS

a. Chalk




F STRATA.
FEET.
300
400
500
ALLUVIAL STRATA.
(ANCIENT)
Isle of Wight.
I. ALLUVIAL
Detritus
II. TERTIARY
a. Upper Freshwater
b. Upper Marine
c. Lower Freshwater
d. London Clay

SECTIONS

Feet 6 0 1 2 3

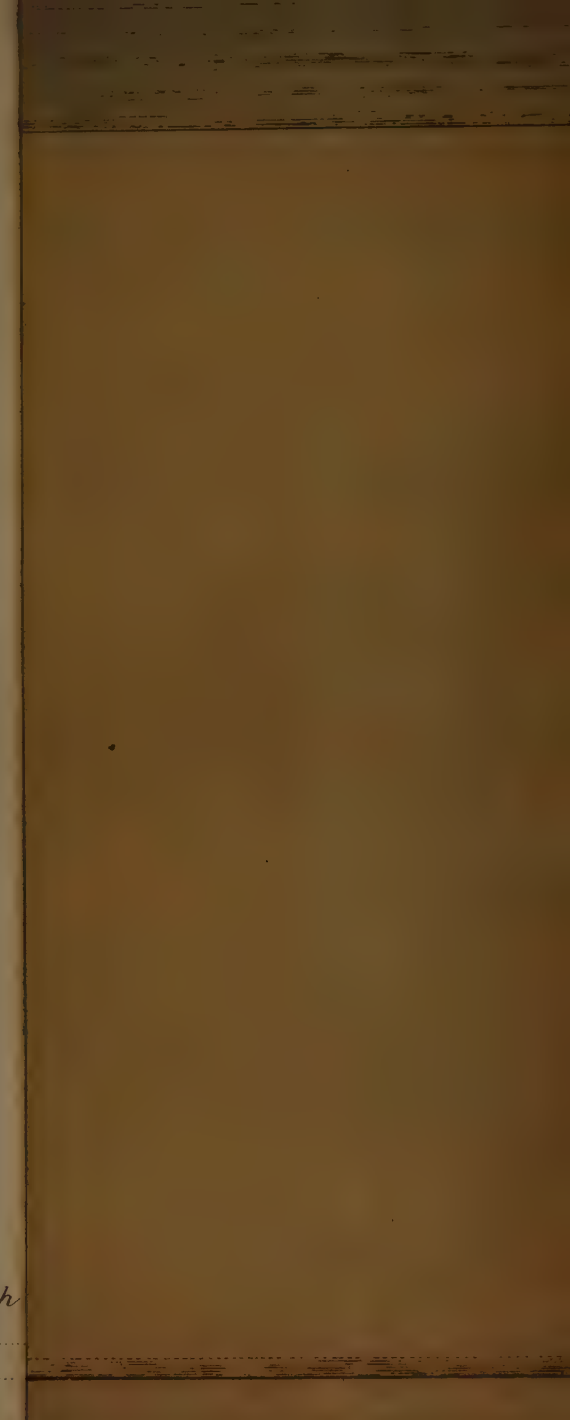
3. .... D° .... with flints.............................

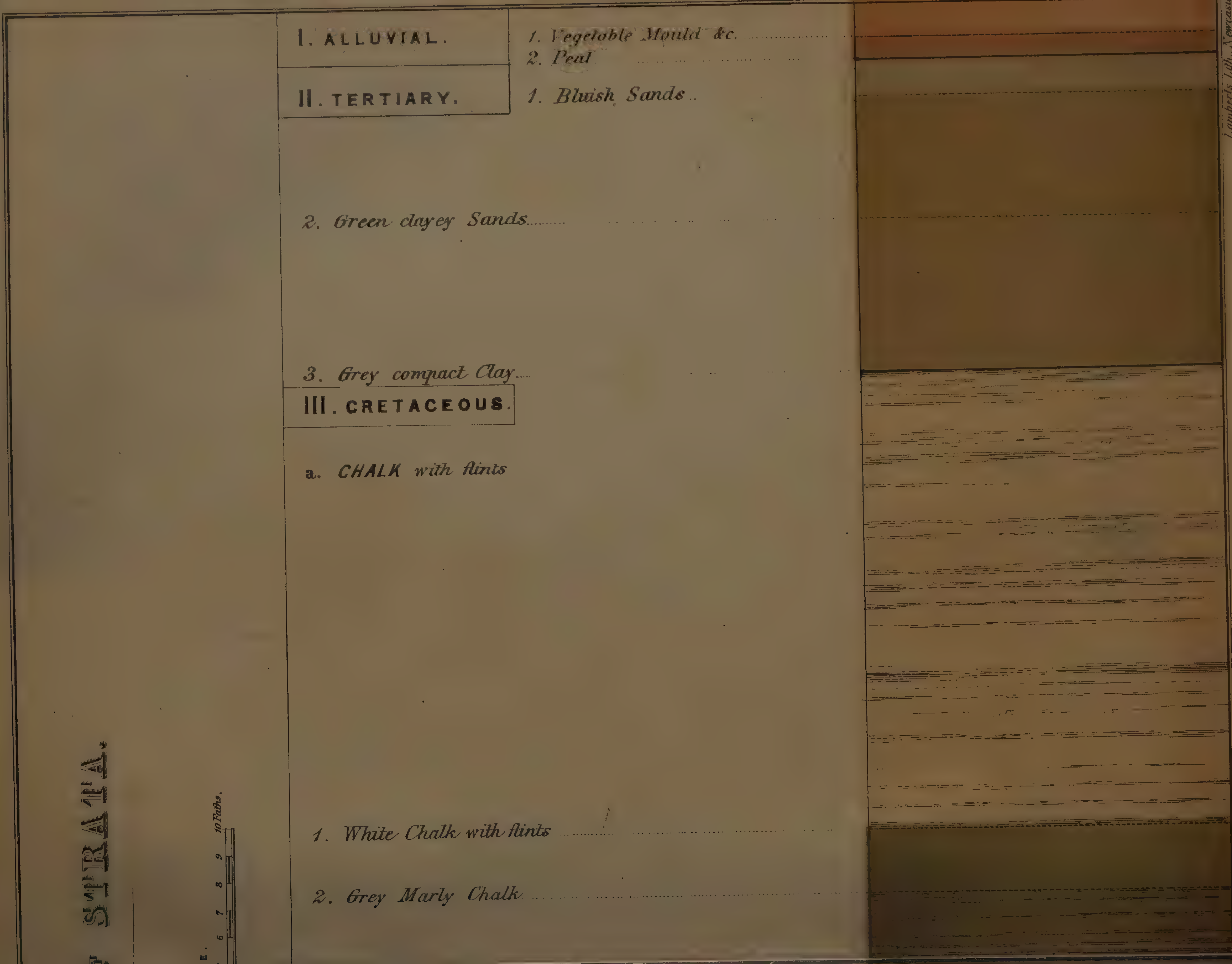
d. UPPER GREENSAND: (?)

1. "Dièves" (Beds of clay, usually green, sometimes reddish impermeable to water.)..............................

2. "Tourtia" (Gravels and rolled flints.)..............................

IV. COAL MEASURES.





STRATA.
E.
6 7 8 9 10 Faths.
I. ALLUVIAL.
1. Vegetable Mould &c.
2. Peat
II. TERTIARY.
1. Bluish Sands
2. Green clayey Sands
3. Grey compact Clay
III. CRETACEOUS.
a. CHALK with flints
1. White Chalk with flints
2. Grey Marly Chalk
J. Lamberts Lith., Newcast

SECTIONS

SC

Feet 6 0 1 2 3 4

1. Red Marl

2. Soft Red Sandstone

3. Calcareo-Magnesian Conglomerate (Millstone)

V. COAL MEASURES.

1. Red and Purple Shale
2. Grey Grit
3. Blue Shale or Metal

4. Mixed "Greys" (grit) and "Clift" (shale or metal)

5. Lightly red stained soft Clift
6. Greys

7. "Pan" (coarse fireclay)

8. Greys
9. COAL

10. Greys
11. Clift

12. GREAT VEIN COAL
13. "Blacks" (blackshale)
14. Hard Greys

15. Greys and Pan

G. C. Greenwell del

STRATA.

6 7 8 9 10 Fathoms

Braysdown, Somersetshire.

I. ALLUVIAL. Soil and Broken Stones

II. OOLITIC.

i INFERIOR OOLITE :- Bastard Freestone

III. LIAS.

a. UPPER LIAS :

Grey Marl

b. LIAS MARL-STONE

1. Grey Limestone

2. Corngrit do

3. Sunbed do

4. White Lias do

c. LOWER LIAS :- 1. Grey Marl

2. Dark Shelly Marl

3. D° D° with loose stones

IV. TRIAS.

Lambert lith. Newcastle.

SECTIONS

Feet 6 0 1 2 3 4 5 6

3. *Strong Light Brown Limestone*

4. *Very Strong Grey Limestone (Water 50 Gall.^{s} per Minute)*

5. *Mild Yellow Limestone (Water 45 Gall.^{s} per Minute)*

6. *Strong Brown Limestone (Water 30 Gall.^{s} per Minute)*

7. *Strong Blue Limestone (Dendritic)*

8. *Blue and Grey Marl. (Fish Bed)*

b. Lower New Red Sandstone.

1. *Soft Sandstone or Sand, yellow Water 256 Gall.^{s} per Minute*

III. CARBONIFEROUS.

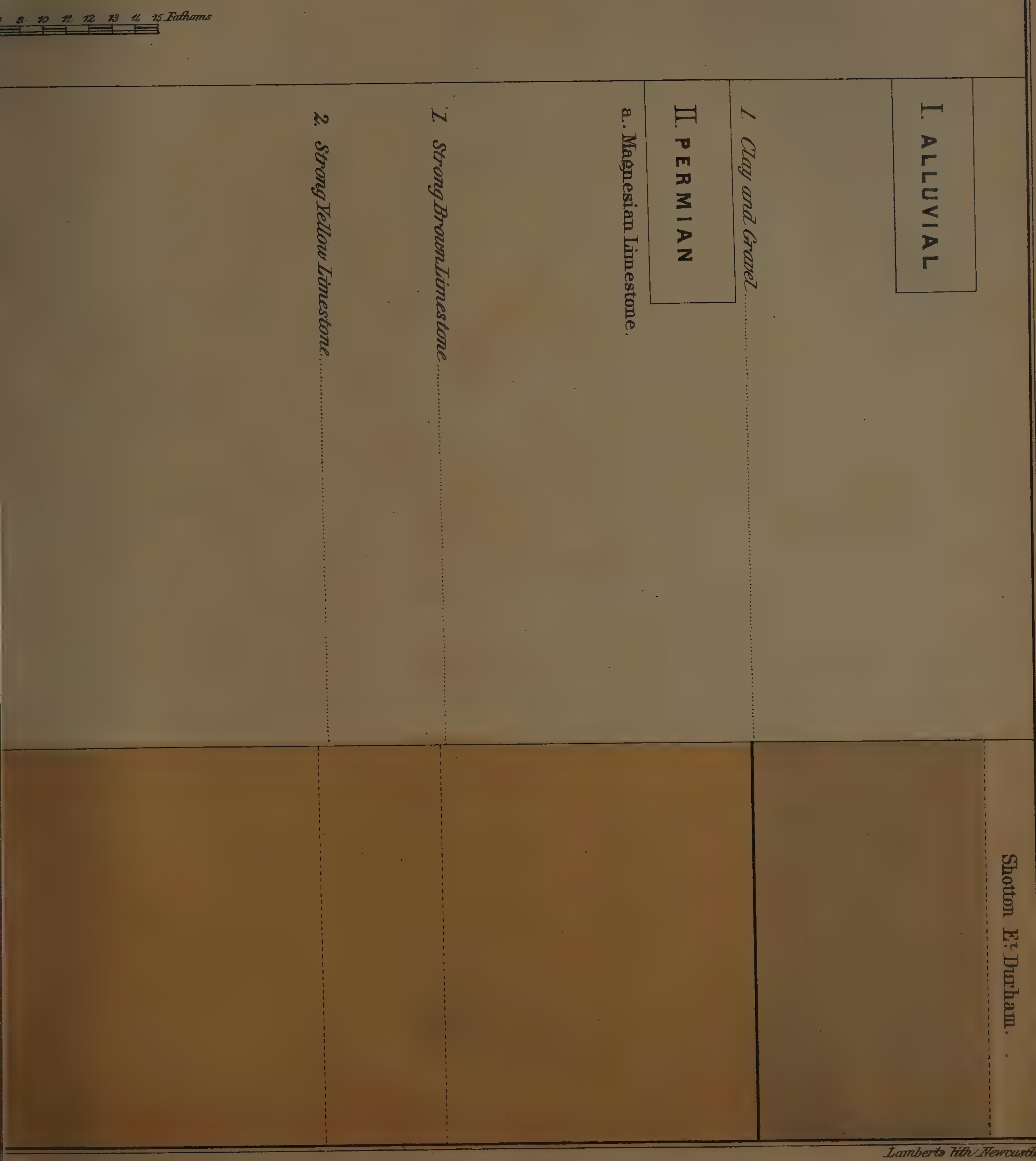
1. *Blue and Brown Post Girdles*
2. *Soft Blue Metal*
3. *Soft Red Metal*

a. Coal Measures

4. *Mild Red and Grey Post*
5. *Whin Girdle*
6. *Mild Grey Metal*
7. *Mild Grey Post Girdle*
8. *Blue and Red Metal*
9. *Blue Metal*
10. **COAL** *will not ignite, but looks bright; very tender*
11. *Red and Grey Metal*
12. *Grey Post*
13. *Strong Coarse White Post*
14. *Red and Blue Metal*
15. *Strong White Post with Red*
16. **COAL**
17. *Strong Thill*
18. *Blue and Grey Metal with Post Girdles*
19. **COAL**
20. *Grey Metal with Girdles*

G. C. Greenwell del

F STRATA.



Lamberts lith. Newcastle

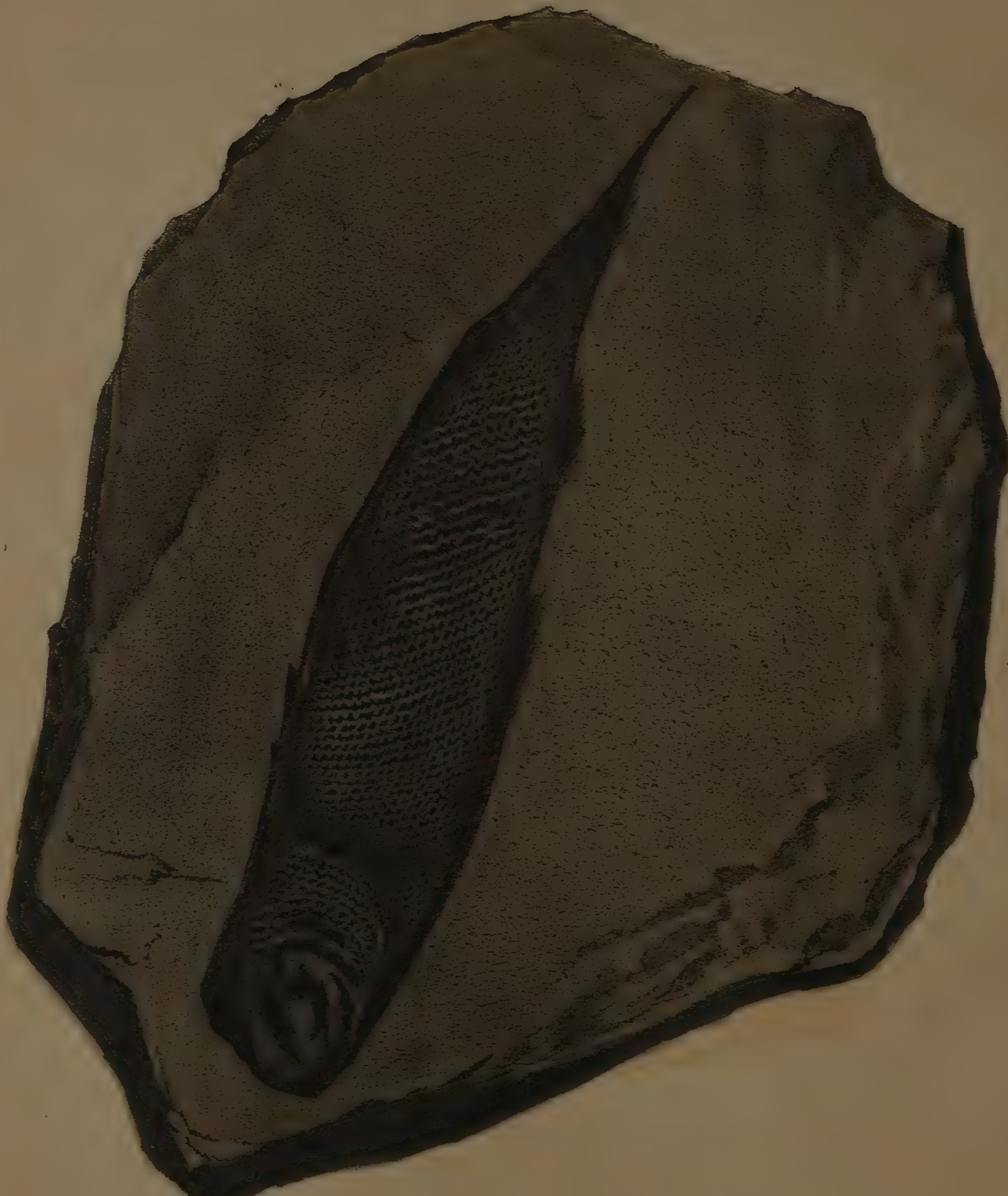


Fig. 1.
Palæoniscus Comtus,
Marl Slate, Shotton Sinking.

G.C. Greenwell del.

EMAINS.

Fig. 2.

Palæoniscus ?

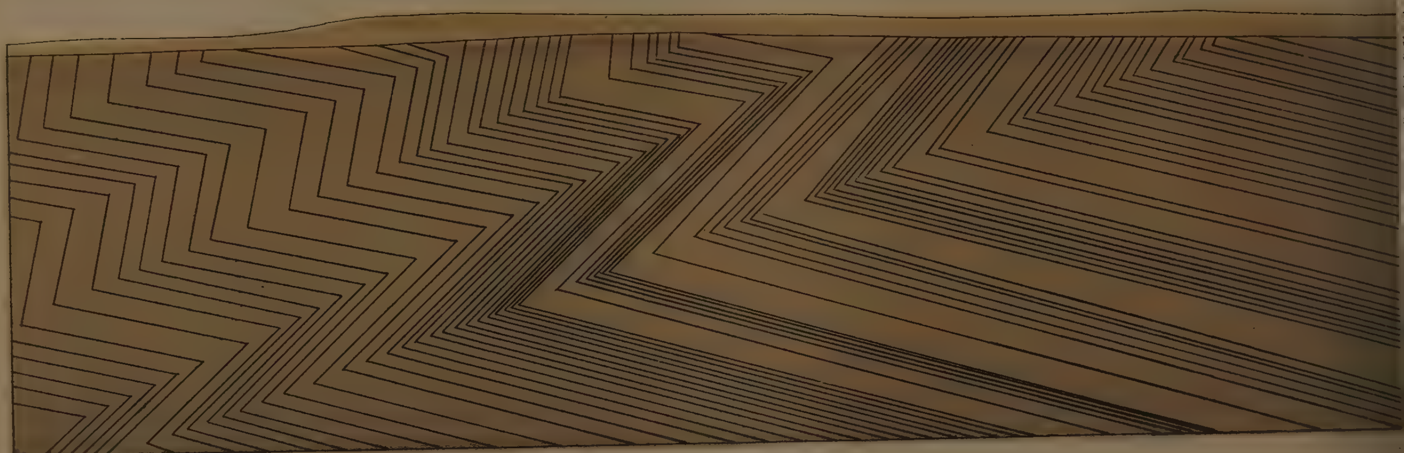
Marl Slate, Thickley Quarry.

Lamberts lith. Newcastle

SECTIONS

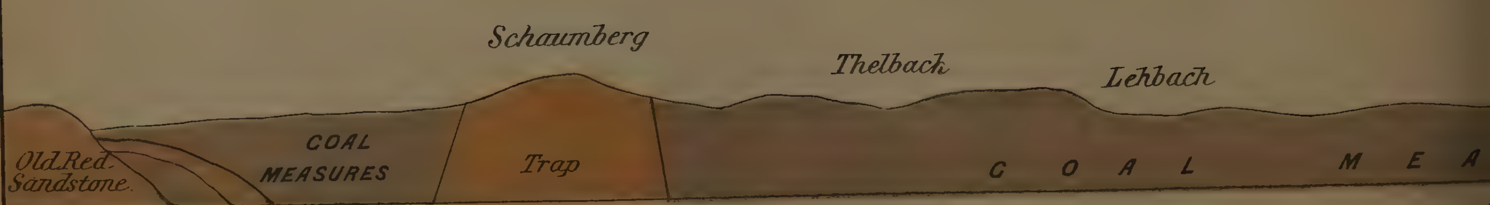
COALFIELD

MONS D



SAARBRUCK

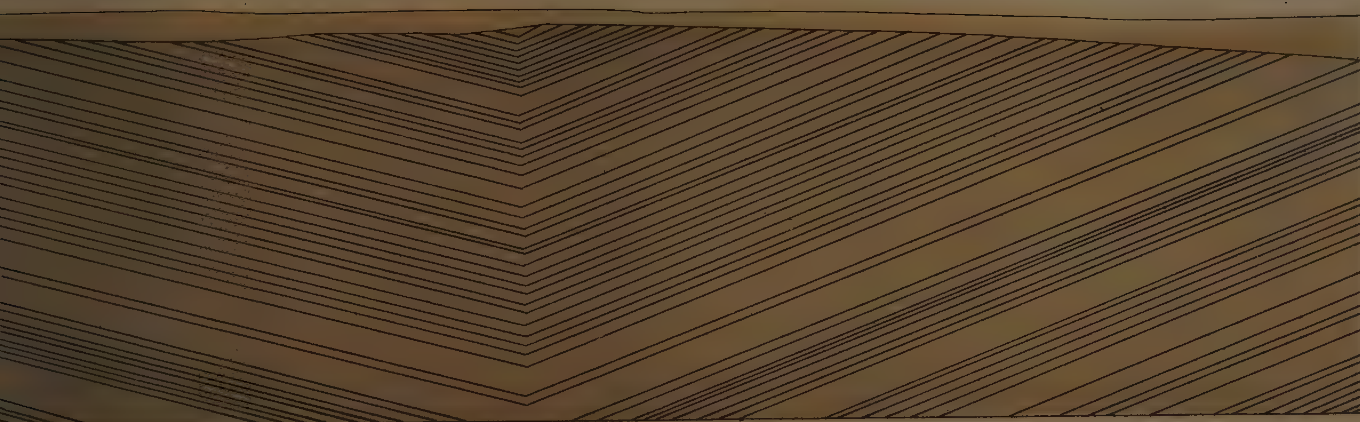
RHENISH



G. C. Greenwell, del.

F STRATA.

F BELGIUM,
STRICT.



.1.

COAL FIELD,
PRUSSIA.

2.

SECTIONS

FIG. 1.

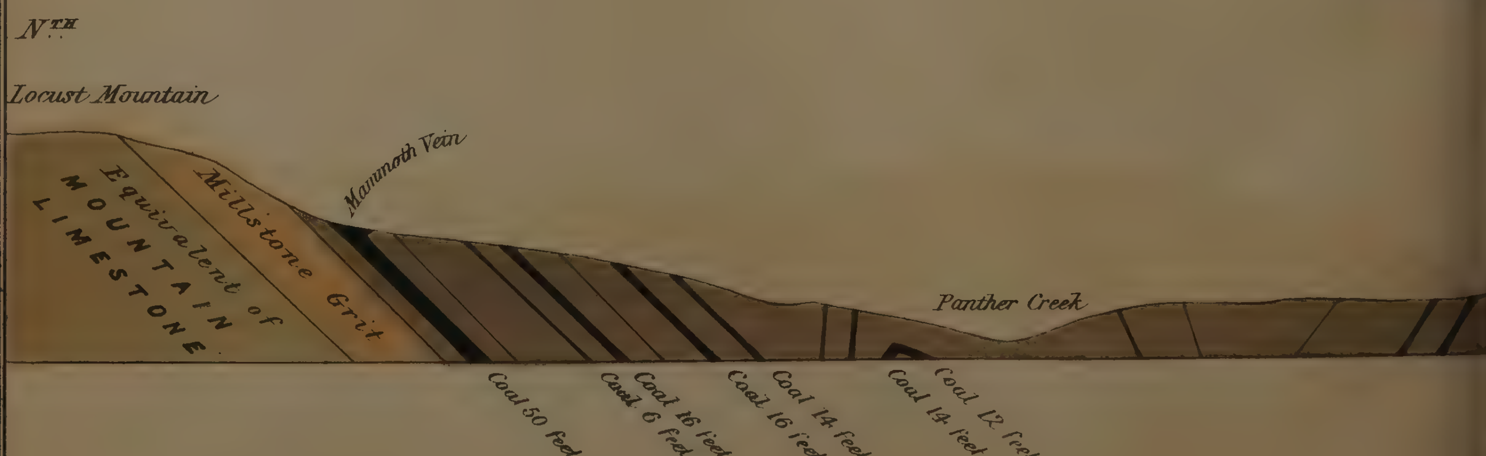
COAL FIELD OF ST ÉTIENNE,

FRANCE.

FI

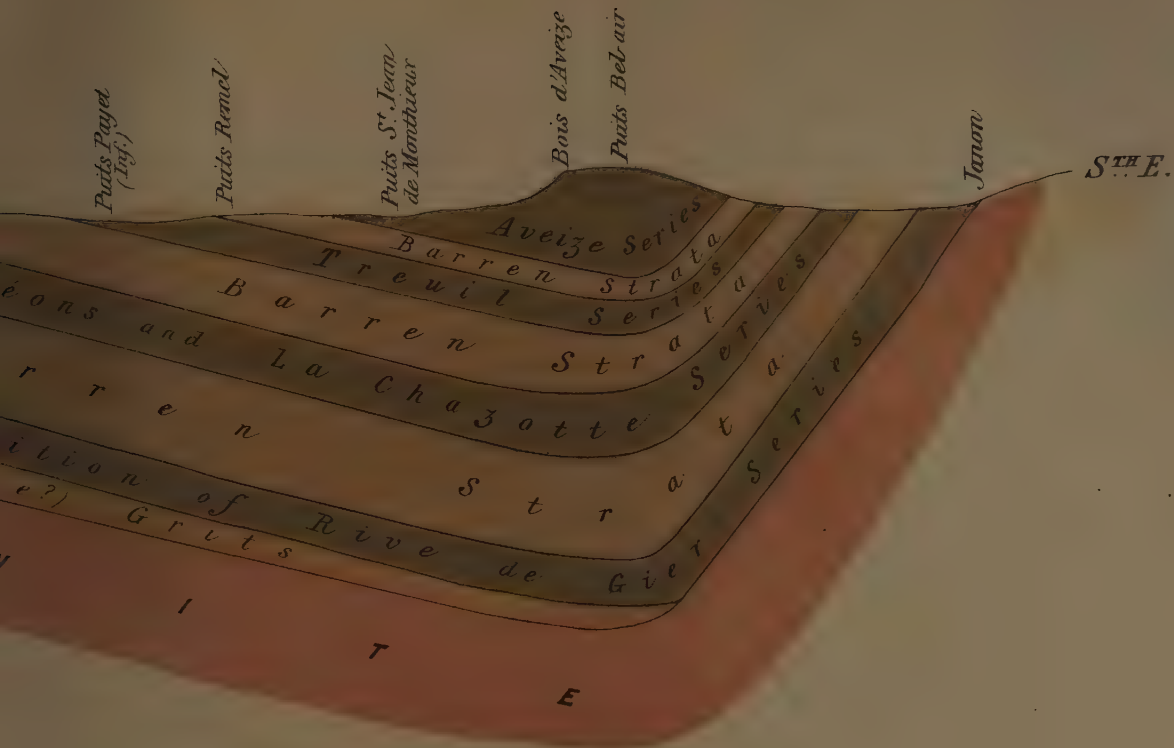
COAL FIELD OF

(ANTHR



G. C. Greenwell del

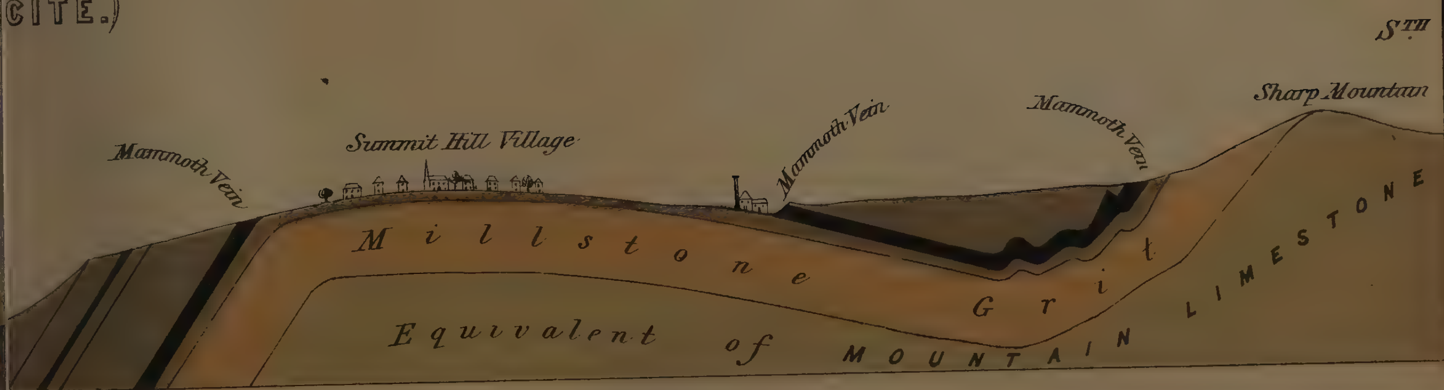
STRATA.



2

ENNSYLVANIA.

CITE.)

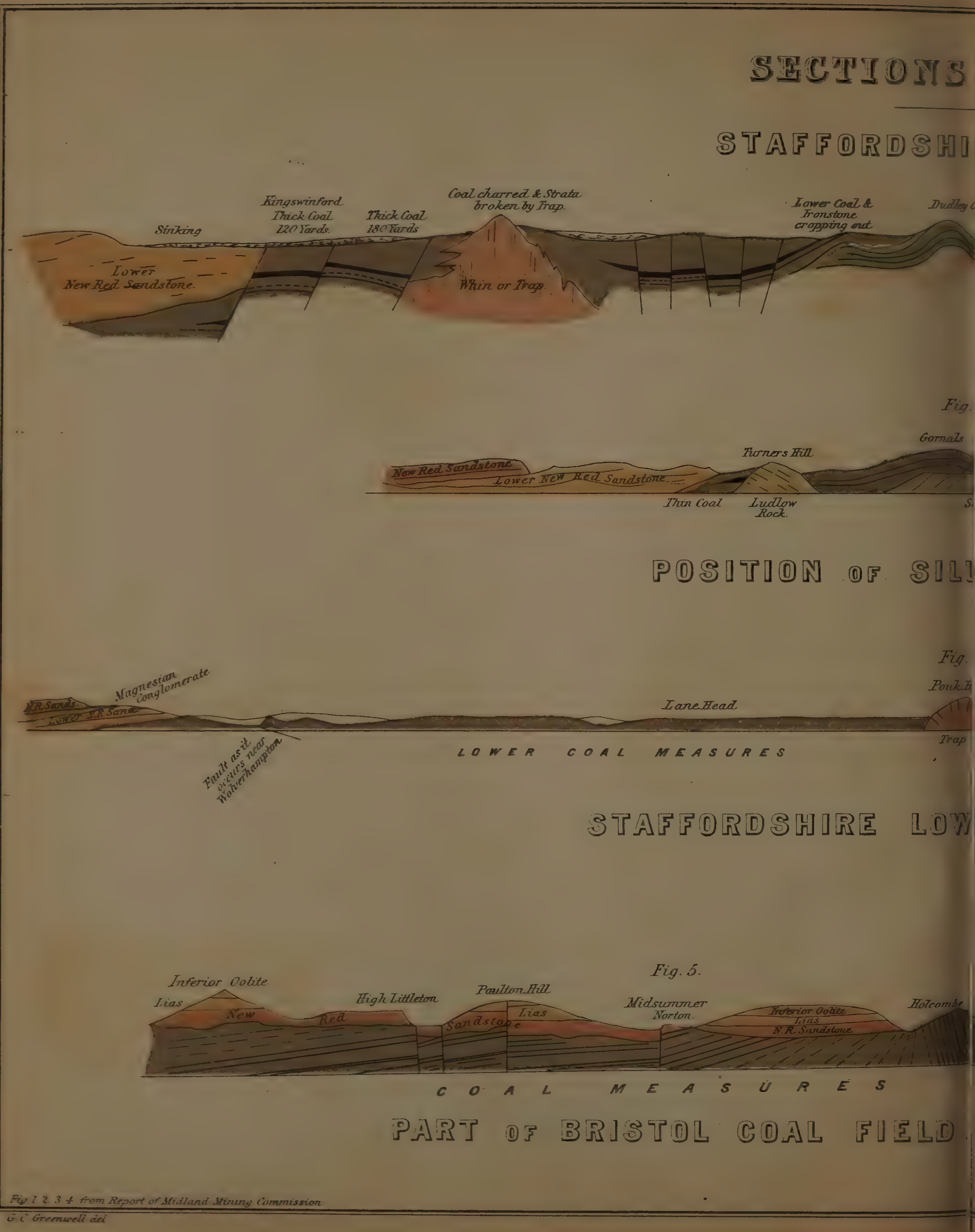


Lamberts lithog Newcastle

G. C. Greenwell. del.

Lamberts Lith. Newcastle.

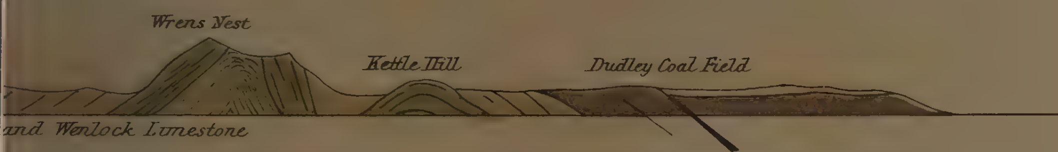

SCOTLAND
Glasgow
EDINBURGH
Berwick
Newcastle
Durham
Whitehaven
Cleveland


SECTIONS
STAFFORDSHI
Coal charred & Strata broken by Trap.
Kingswinford Thick Coal 120 Yards.
Thick Coal 180 Yards
Sinking
Lower Coal & Ironstone cropping out
Lower New Red Sandstone.
Whin or Trap.
Fig.
Gornals
Turners Hill
New Red Sandstone
Lower New Red Sandstone
Thin Coal
Ludlow Rock.
POSITION OF SIL
Fig.
Magnesian Conglomerate
N.R. Sands.
Lower N.R. Sand
Lane Head
Trap
Fault as it occurs near Wolverhampton
LOWER COAL MEASURES
STAFFORDSHIRE LOW
Fig. 5.
Inferior Oolite
Lias
High Littleton
Paulton Hill
New Red Sandstone
Lias
Midsummer Norton.
Inferior Oolite
Lias
N.R. Sandstone
Holcombe
COAL MEASURES
PART OF BRISTOL COAL FIELD
Fig 1. 2. 3. 4. from Report of Midland Mining Commission
G. C. Greenwell del

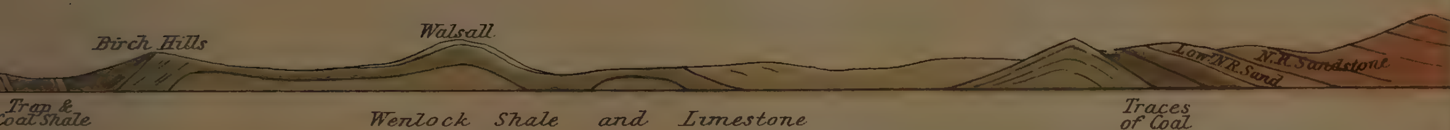
F STRATA.

E THICK COAL.

Fig. 1.



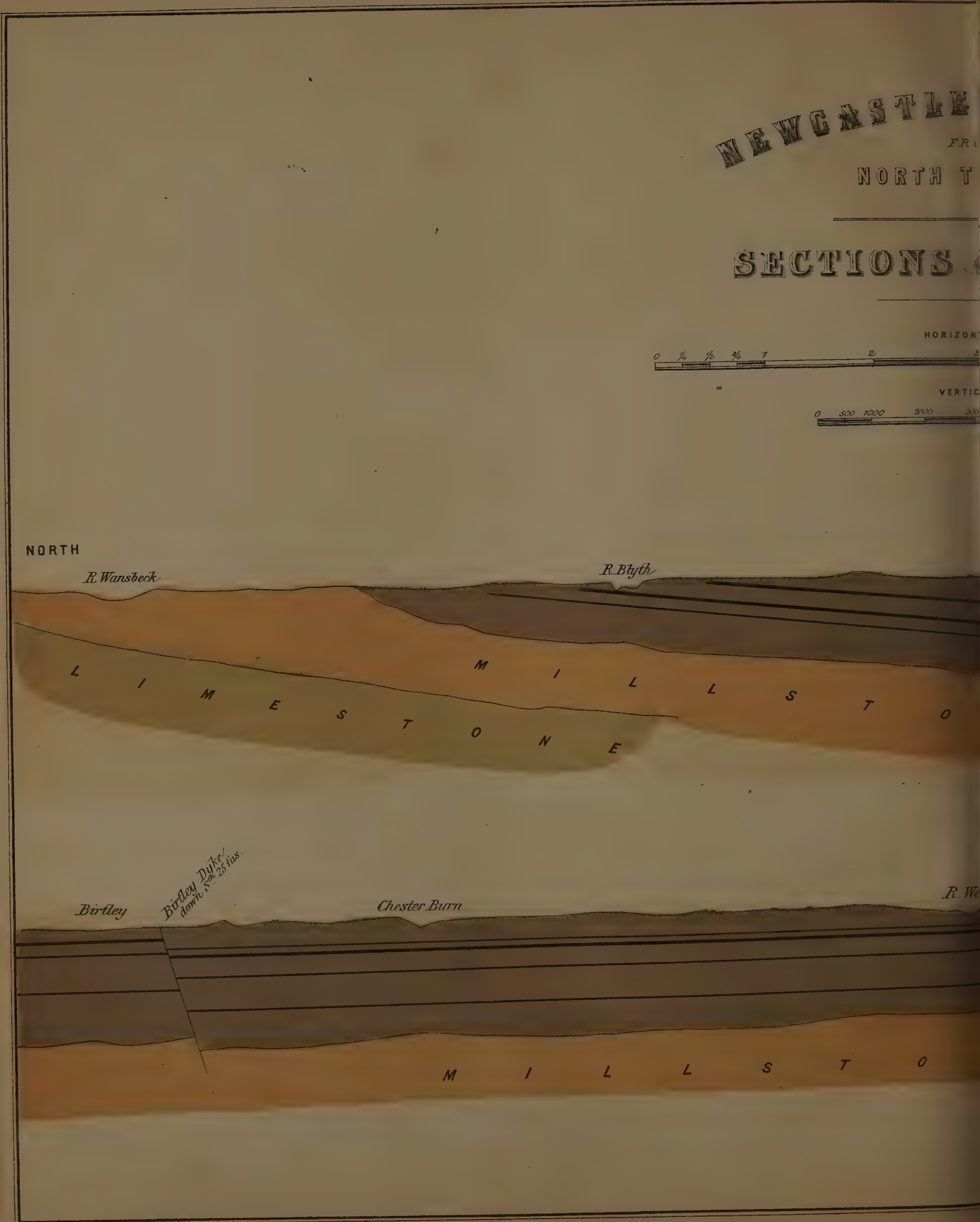
IAN LIMESTONE.



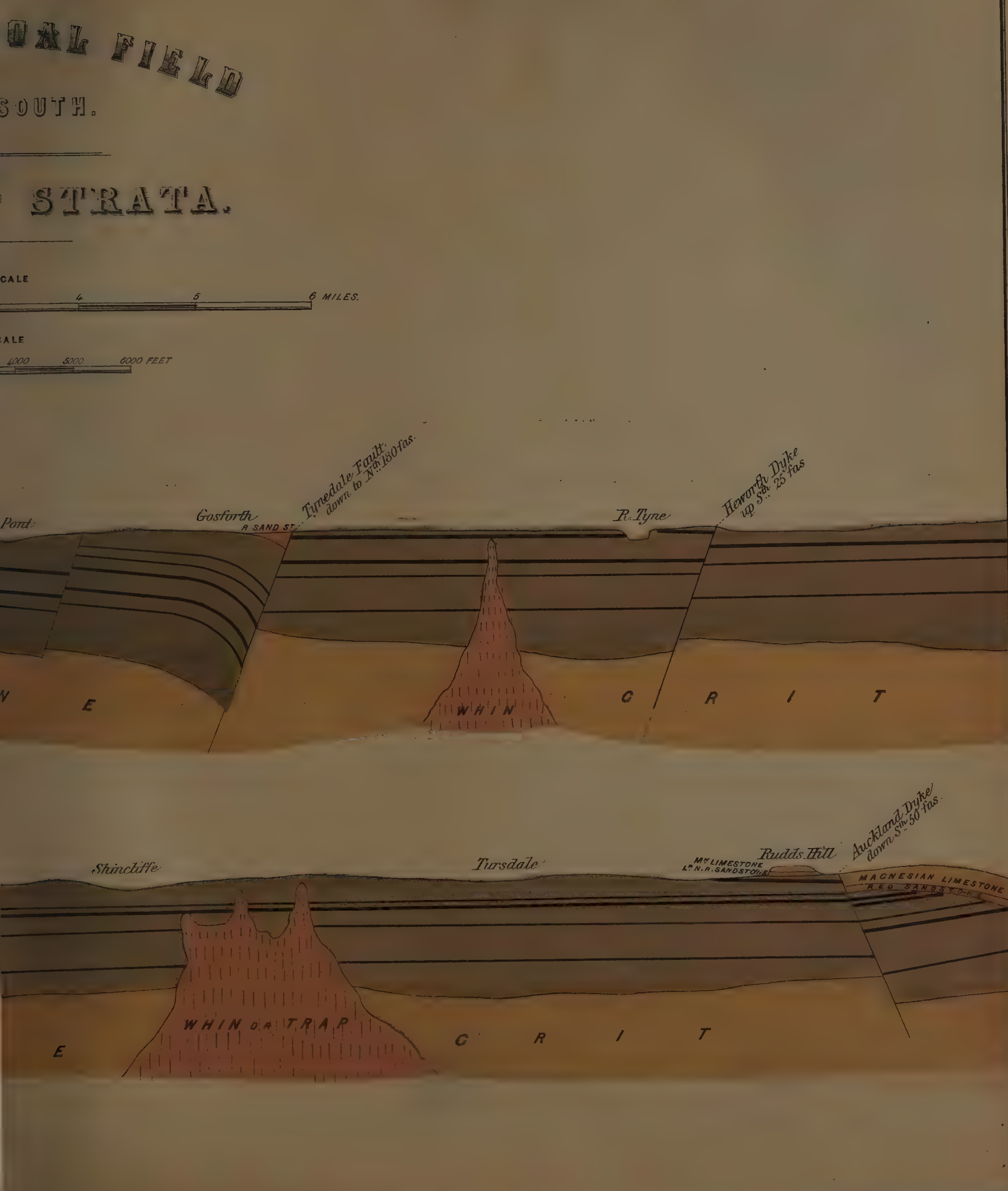
R COAL MEASURES.

Fig. 4.

Lamberts Lith. Newcastle.



G. C. Greenwell del



Lamberts lith. Newcastle

ORGANIC

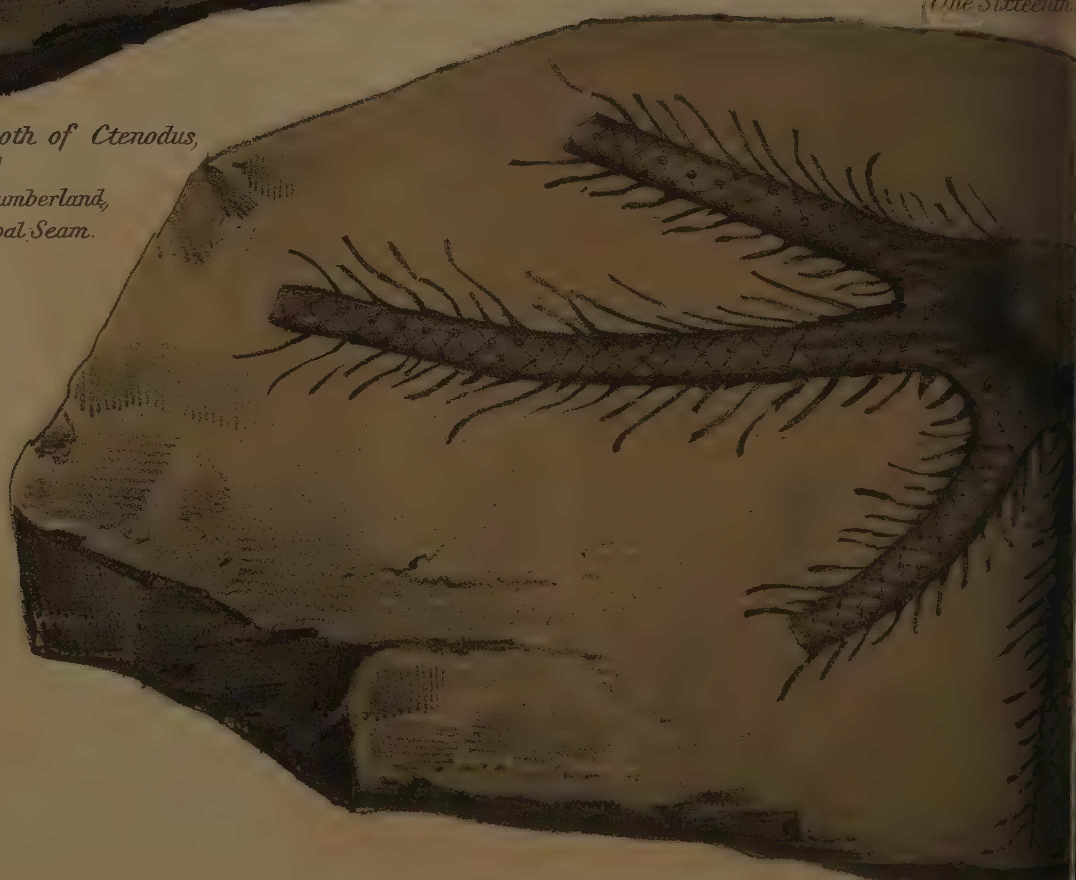
Fi
Gyracanthus Auckland

Roof of Fivequarter Seam
(Natura

Fig. 3.

Mandible and Compound Tooth of Ctenodus,
(Natural Size)
Newsham Colliery, Northumberland,
Shale of Low Main Coal Seam.

Fi
Root of Sigillaria (?) Roof of Fivequ
(One Sixteenth



Stigmari

G. C. Greenwell del.

MAINS.

s (Dorsal Spine).

tal) Blackboy Colliery.
e.)

Fig. 4.

Palate Tooth of Ctenodus,
(Natural Size)
Newsham Colliery, Northumberland,
Shale of Low Main Coal Seam

Seam (Metal) Blackboy Colliery,
ral Size)

coides

Fig. 5.

Lepidostrobus.
(Natural Size)
Newsham Colliery Northumberland
Shale of Low Main Coal Seam

Lamberts Lith Newcastle

ORGANIC

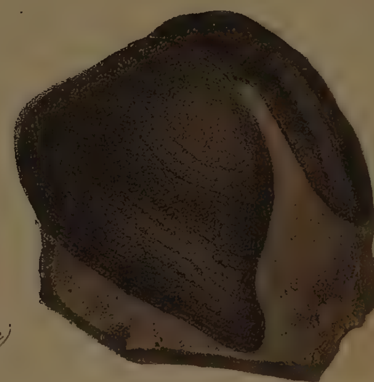


Fig. 1

Anthracosia.

Roof of Bitchburn Seam. (Natural Size)

West Auckland Colliery.

Fig

An

Black Meta

(N

Fig. 4

Pecopteris Heterophylla

Grey Metal. Shotton Sinking

(Natural Size)

G. C. Greenwell del.

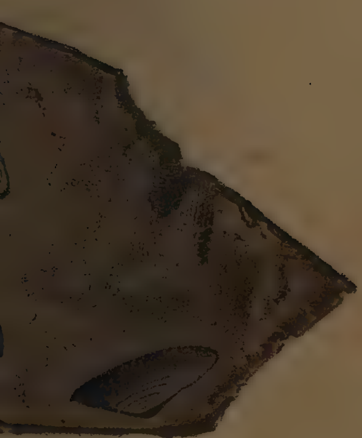
REMAINS.

Fig 2

Trigonocarpum Nöggerathi

Roof of High Main Seam, (Post)

Holywell Colliery (Natural Size)

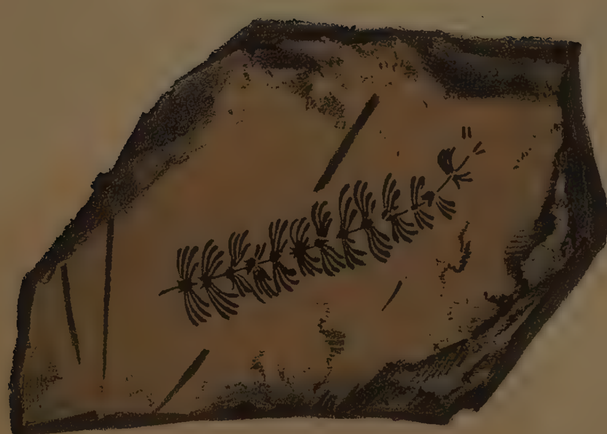


cosia.

hotton Sinking

al Size)

Fig. 5.



Asterophyllites equisetiformis

Grey Metal. Shotton Sinking

(Natural Size)

Lamberts Lith Newcastle

ORGANIC

Fig 1.

Pecopteris

Grey Post Shotton Sinking

(Natural Size)

G. C. Greenwell, delt.

REMAINS.

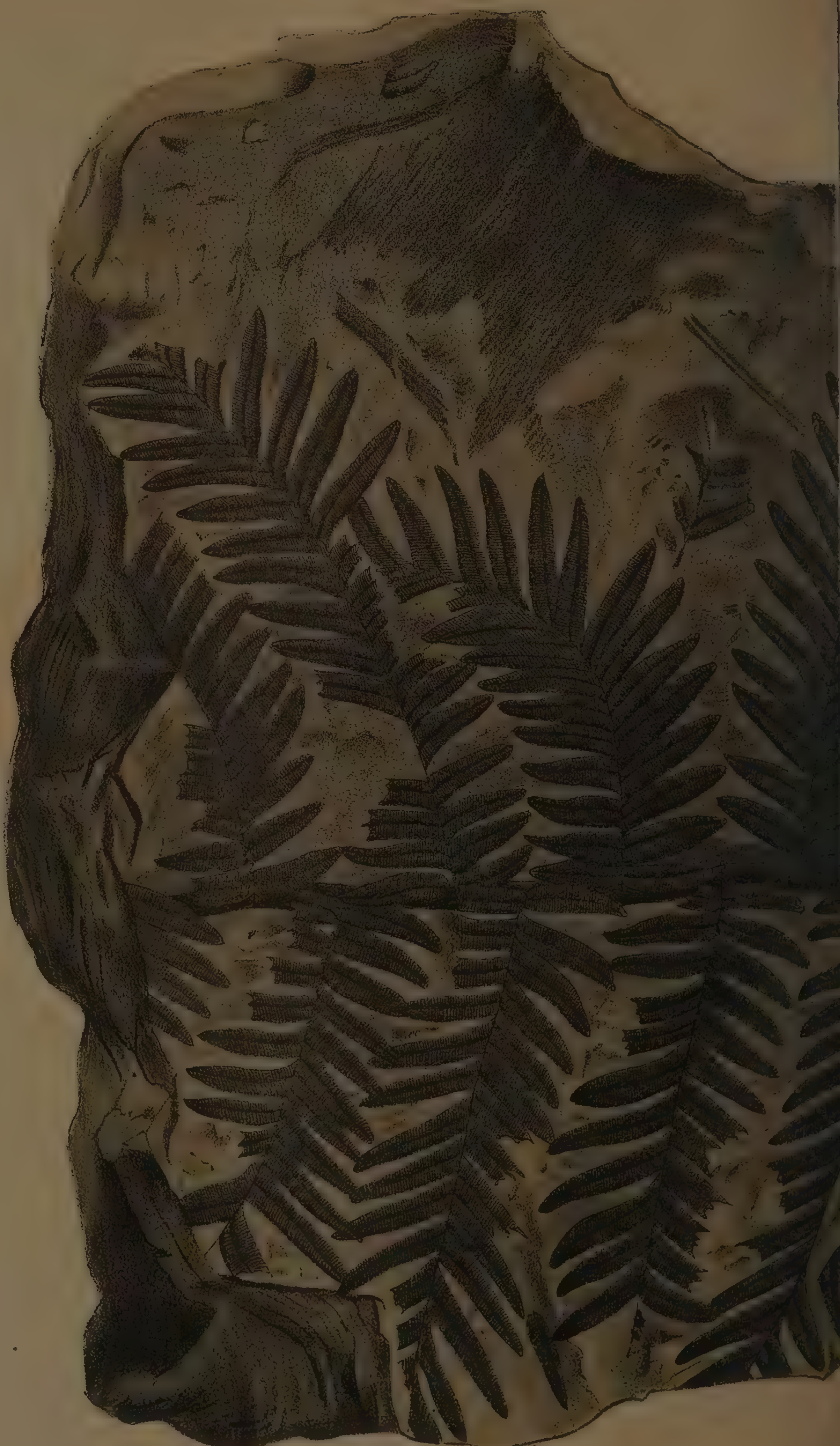
Fig 2

Pecopteris

Grey Metal, Shotton Sinking

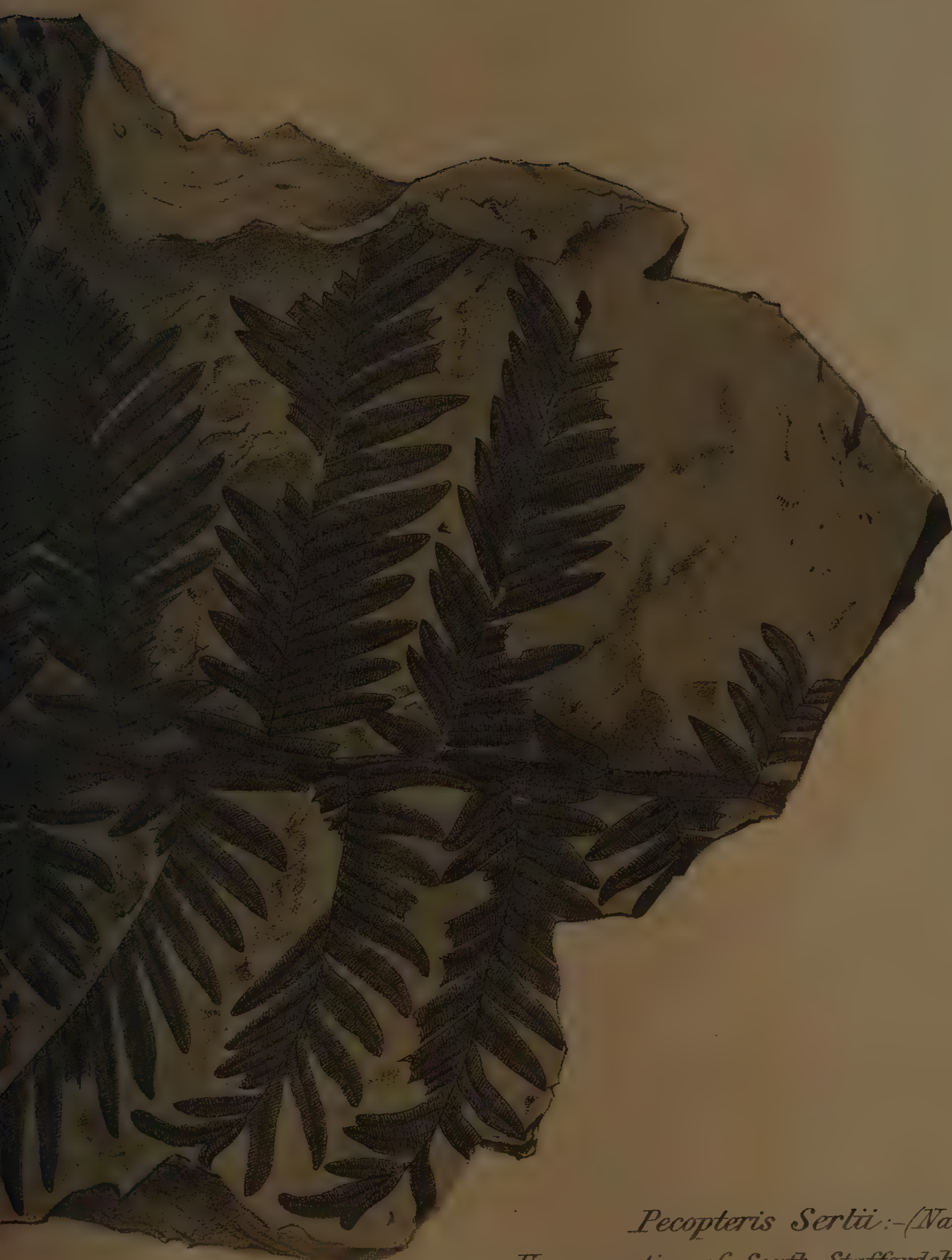
(Natural Size)

Lamberts Lith, Newcastle



H. Johnson del.

RGANIC REMAINS.



Pecopteris Serlii:-(Natural Size)
Upper portion of South Staffordshire Coal Formation
(from the Collection of Mr. Henry Johnson, Dudley

Lamberts Lith. Newcastle

ORGANIC

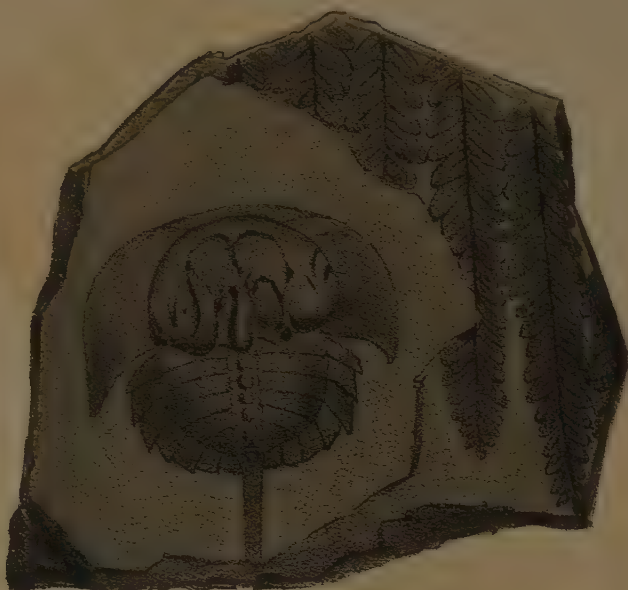


Fig 1.
Prestwichia Rotundata & Neuropteris Elegans,
(Nat: Size) Camerton Colliery_Bath
Radstock Series; Bristol Coalfield

Fig. 6
Neuropteris acutifolia (Nat: Size)
Farringdon Series,_Bristol Coalfield

Fig. 3
Pecopteris:-(Nat: Size)
Radstock Series_Radstock

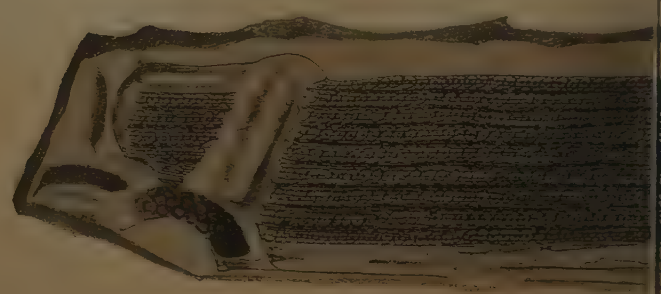


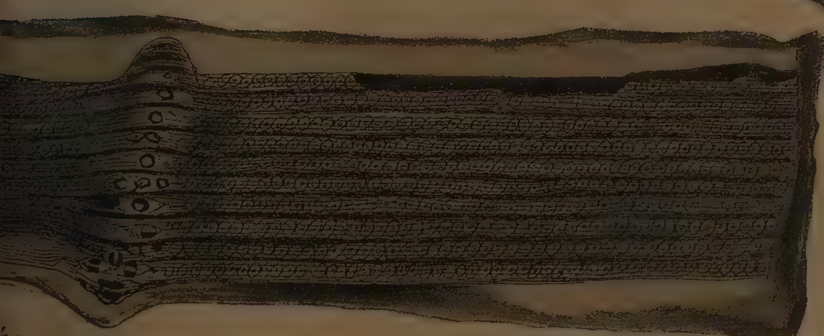
Fig: 4
Sigillaria (Nat: Size) Radstock Series_Rads

G.C. Greenwell del.

REMAINS.

Fig. 2
Neuropteris Heterophylla,
(Nat. Size) Radstock Series:
Radstock.

Fig. 5
Asterophyllites equisetiformis (Nat: Size)
Radstock Series: Radstock.

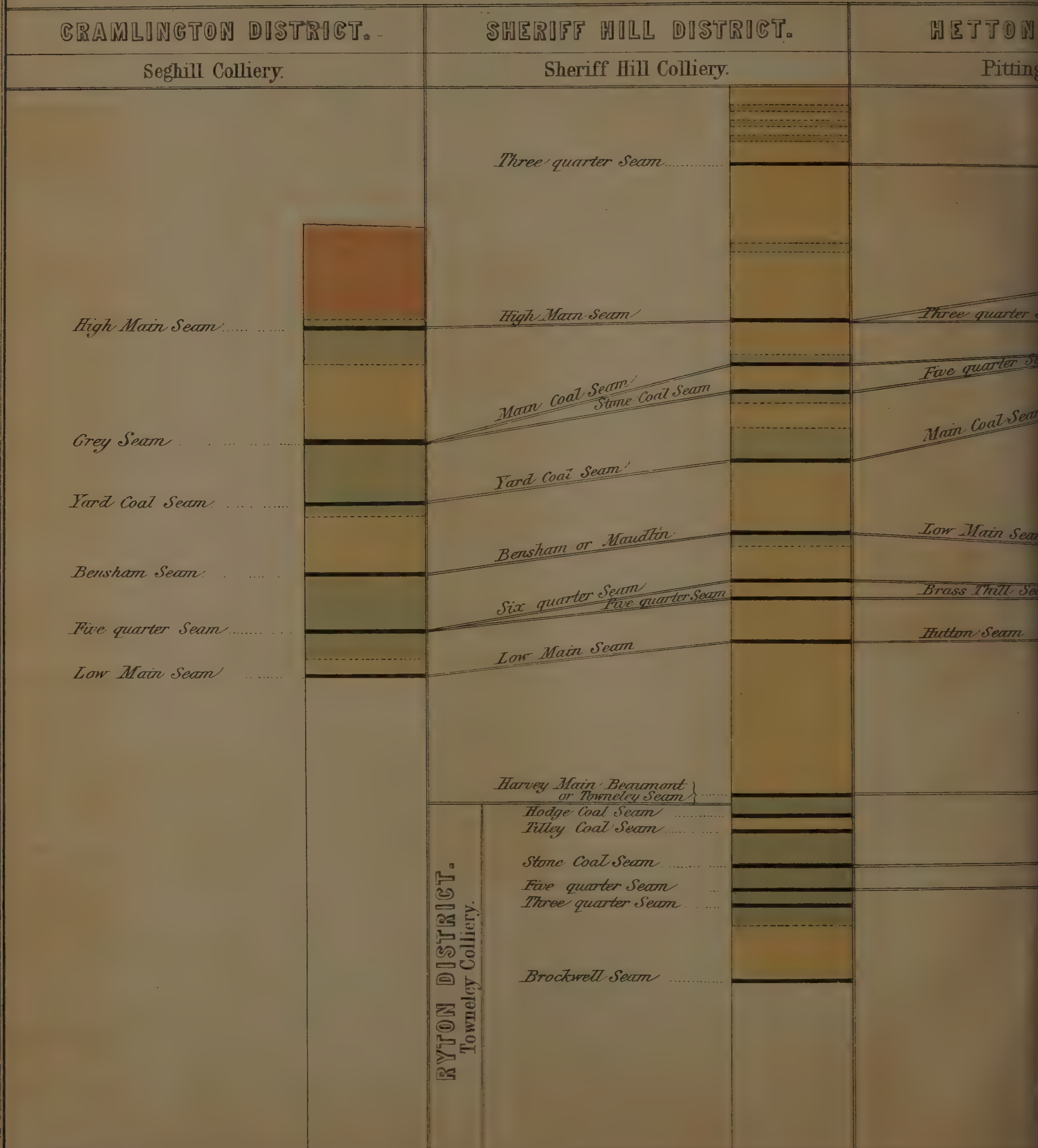


Lamberts Lith Newcastle

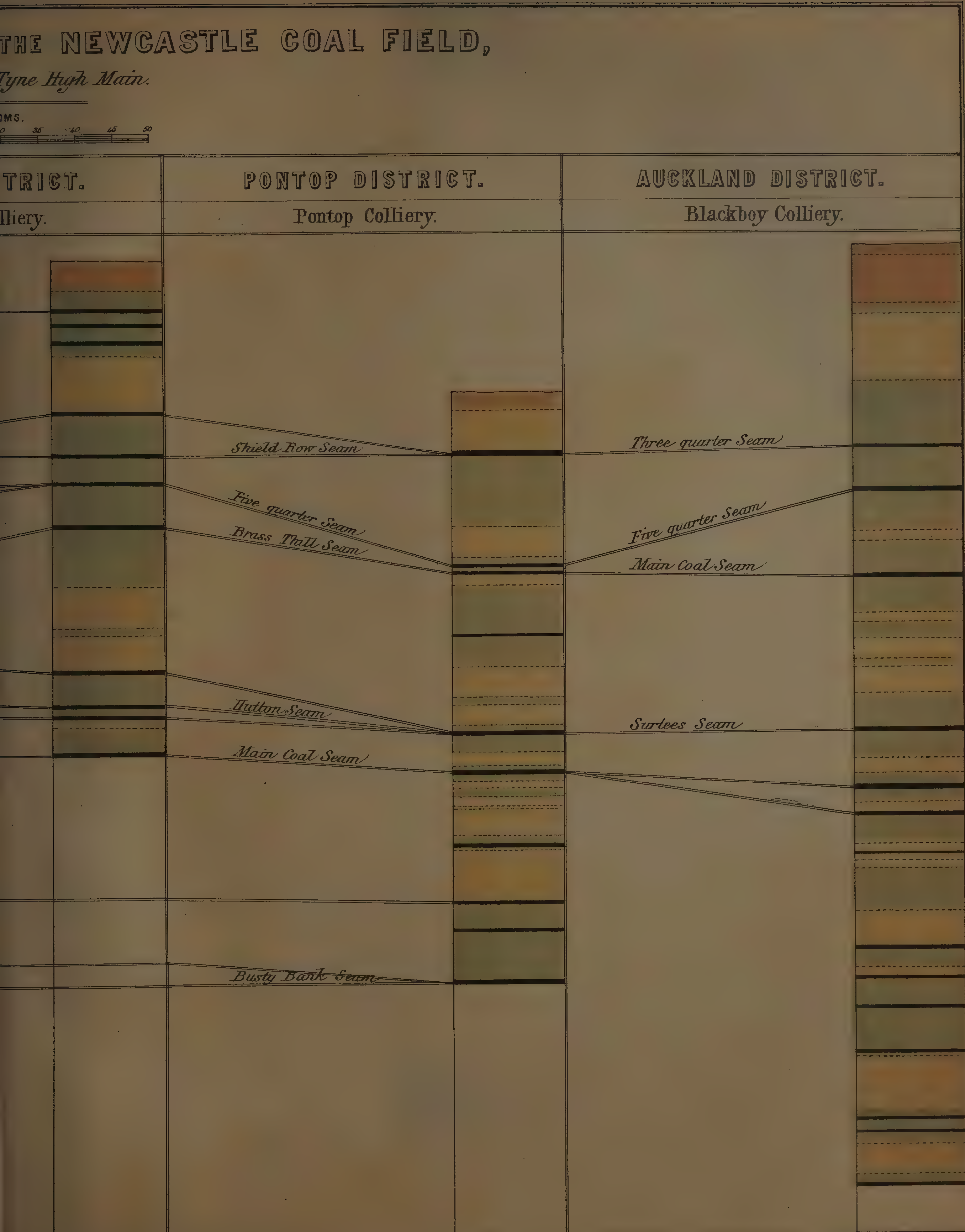
SYNOPSIS OF SEAMS OF COAL

Dating from Leve

SCALE



G. C. Greenwell del.



Lamberts lith Newcastle

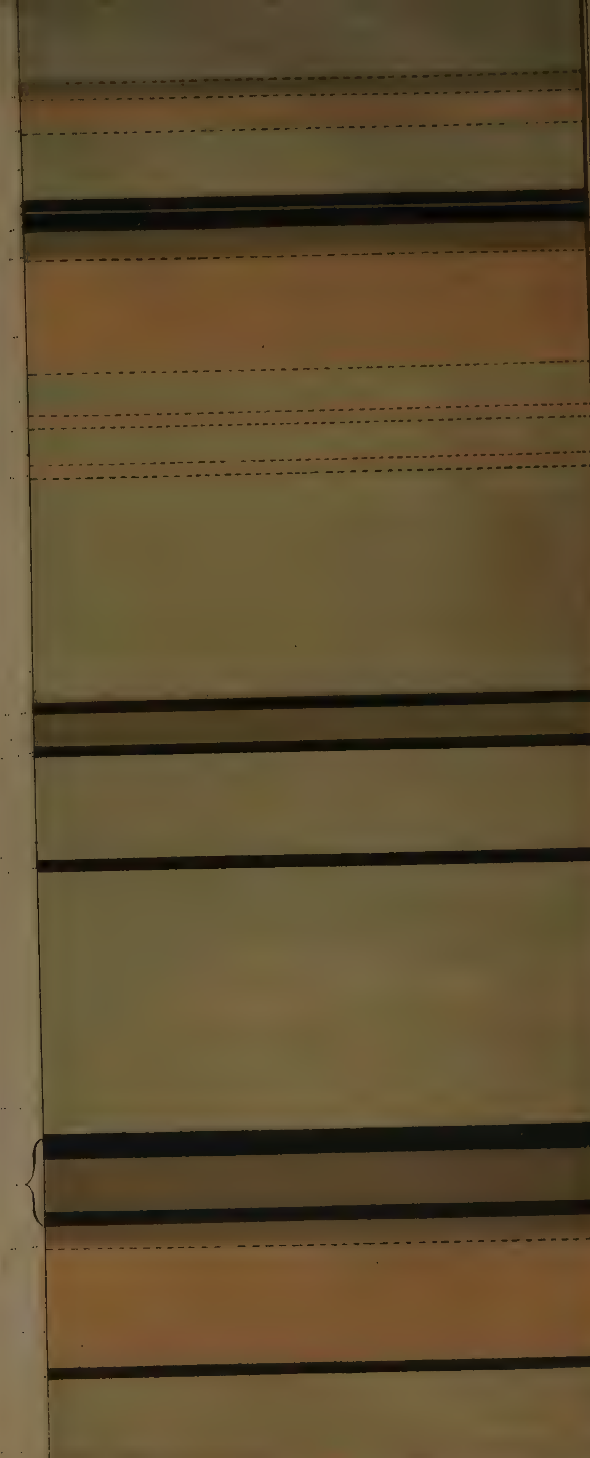
SECTIONS

SCALE

0 1 2 3 4

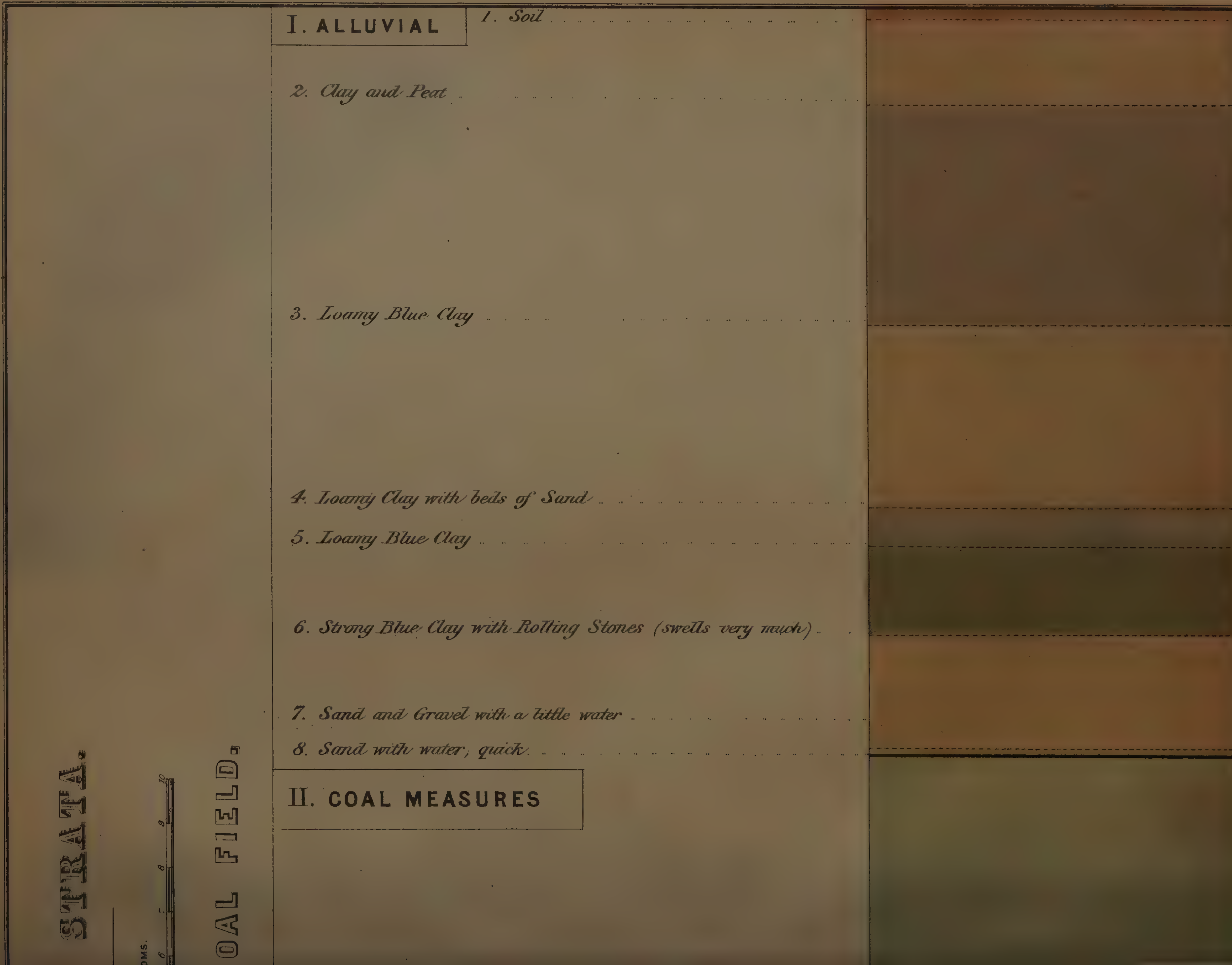
NEWCASTLE

1. *Soft Blue Metal (first 10 feet, rest harder)*
2. *Soft Black Stone*
3. *Grey Post*
4. *Grey Metal*
5. **COAL**
6. *Band*
7. **COAL**
8. *Thill Stone*
9. *Grey Post*
10. *Grey Metal*
11. *Post Girdle*
12. *Grey Metal*
13. *Post Girdle*
14. *Grey Metal*
15. **COAL**
16. *Fire Clay (not good)*
17. **COAL**
18. *Grey Metal*
19. **COAL**
20. *Dark Grey Metal*
21. **COAL** *good*
22. *Band* — **BEAUMONT SEAM**
23. **COAL** *good*
24. *Thill Stone*
25. *White Post*
26. **COAL**
27. *Blue Metal*



G. C. Greenwell del.

Norwood New Pit



Lamberts lith Newcastle

SECTIONS

SECTION OF STRATA AT NORWOOD COLLIERY.

Fig. 1_ Prior to the formation of the Valley as in Fig. 2.

Fig. 2_ Prior to the Silting up of the Valley by the River

Scale of Depths in Fathoms of N.os 1, 2 & 3.

0 1 2 3 4 5 10 15 20

G. C. Greenwell del.

OF STRATA.

Fig. 3 _ The Valley Silted up in its present condition

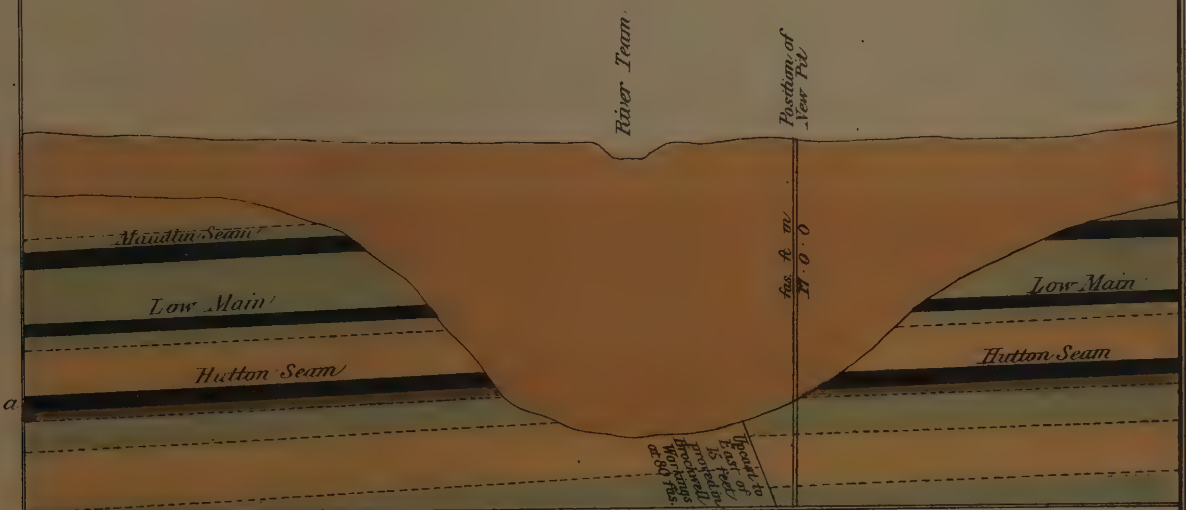
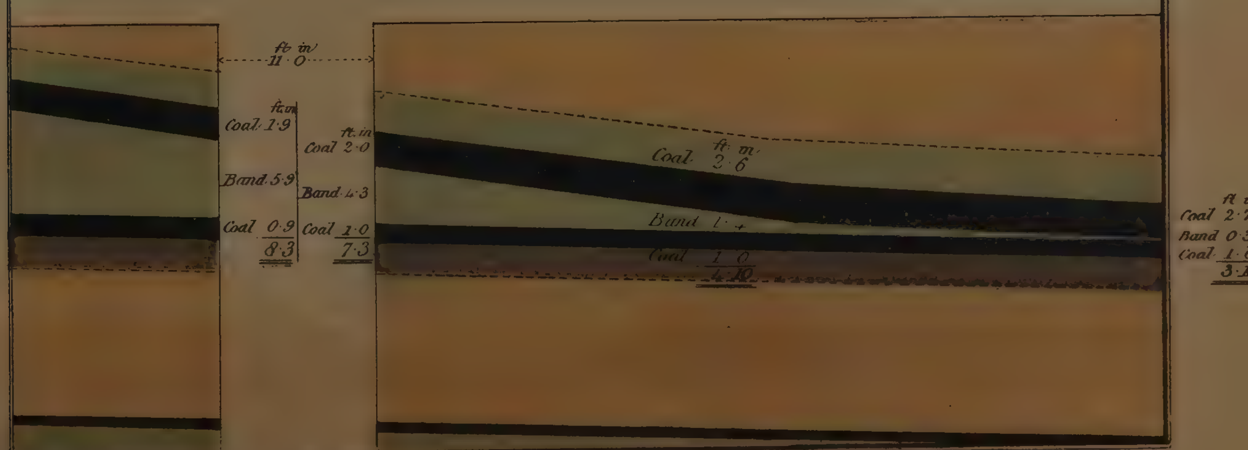
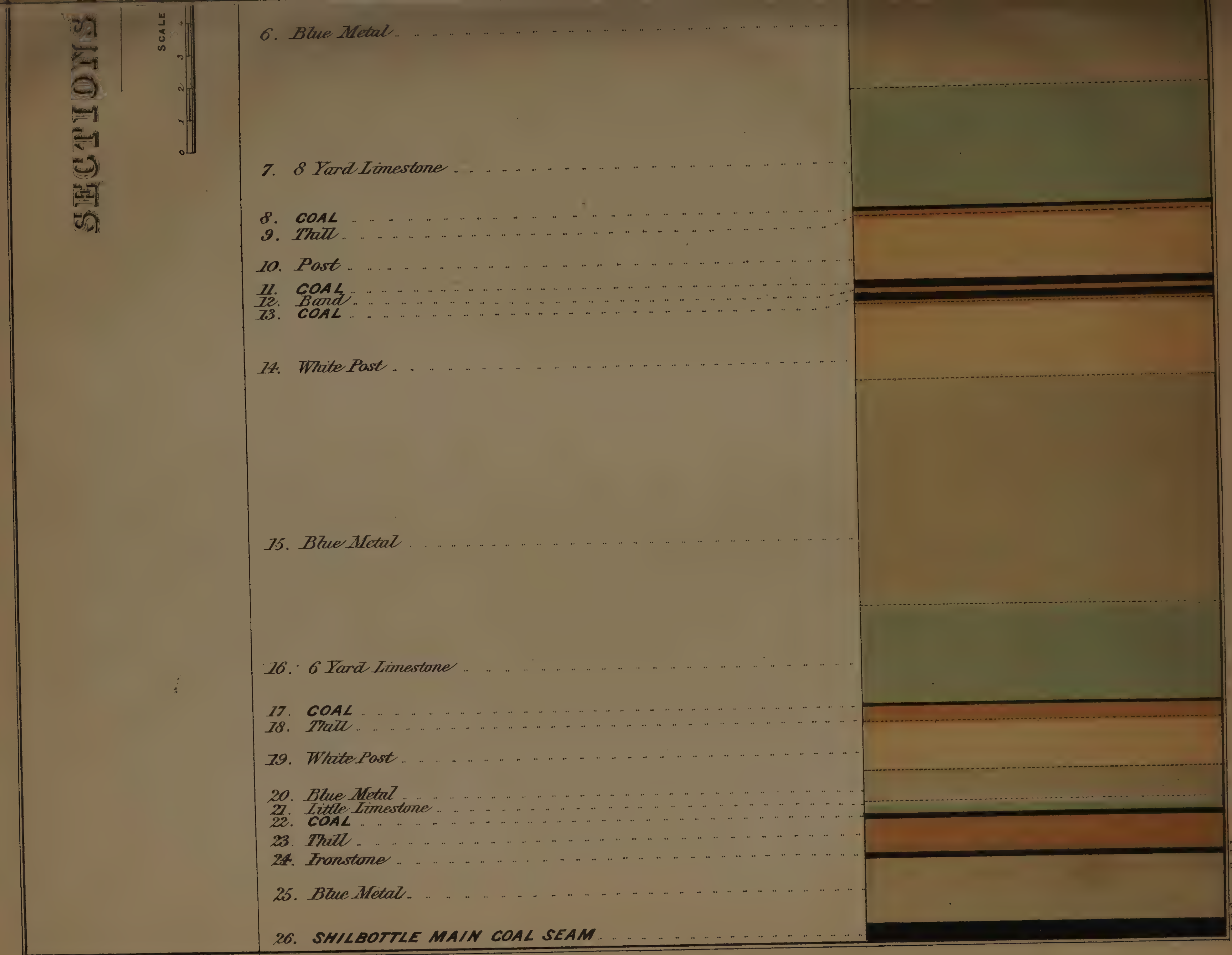


Fig. 4 _ SECTION OF BEAUMONT SEAM.

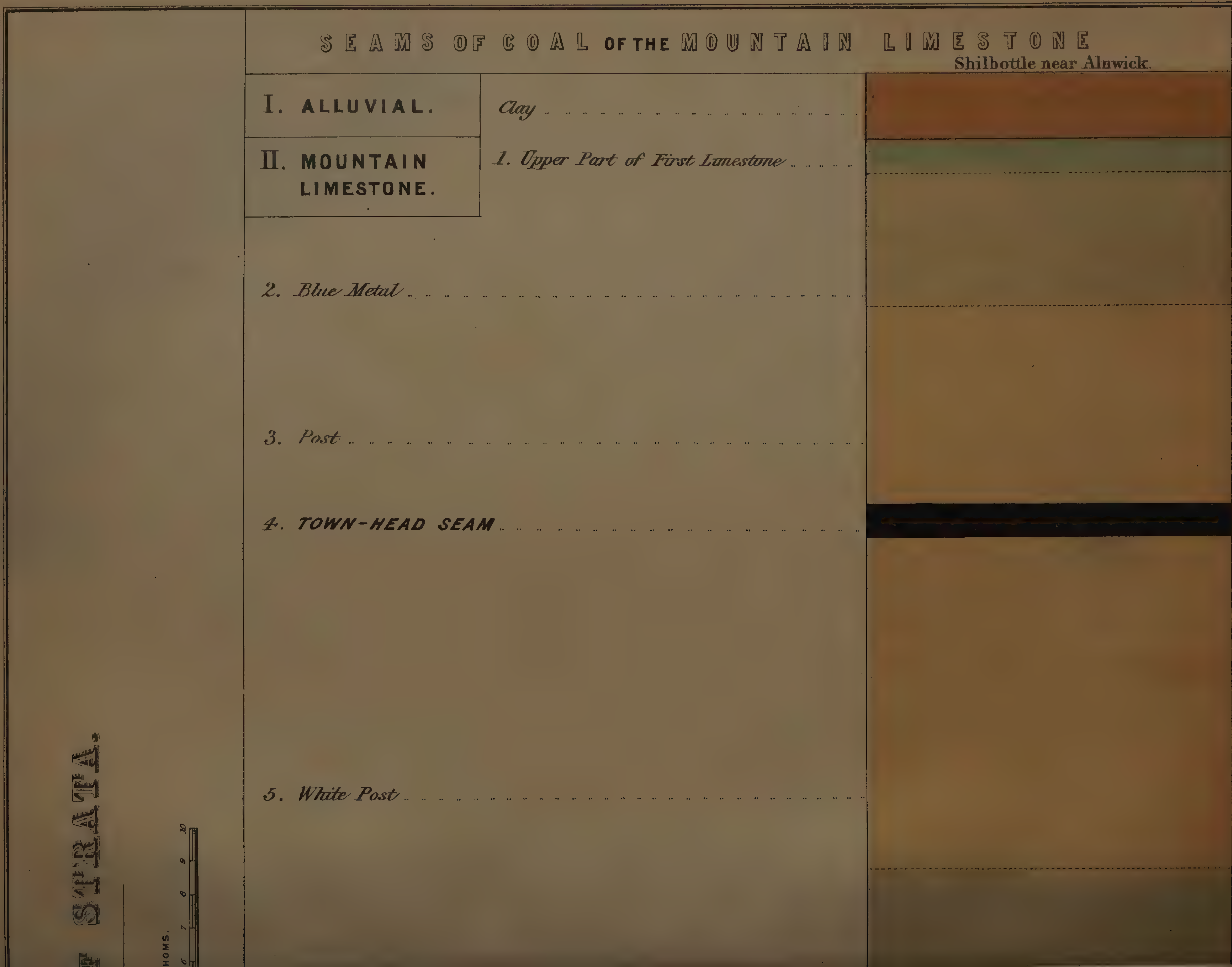
New Pit, Norwood Colliery.



Lamberts, lith. Newcastle



SECTIONS
SCALE
0 1 2 3 4
6. Blue Metal
7. 8 Yard Limestone
8. COAL
9. Thill
10. Post
11. COAL
12. Band
13. COAL
14. White Post
15. Blue Metal
16. 6 Yard Limestone
17. COAL
18. Thill
19. White Post
20. Blue Metal
21. Little Limestone
22. COAL
23. Thill
24. Ironstone
25. Blue Metal
26. SHILBOTTLE MAIN COAL SEAM
G. C. Greenwell del



F STRATA.
HOMS.
6 7 8 9 10
SEAMS OF COAL OF THE MOUNTAIN LIMESTONE
Shilbottle near Alnwick.
I. ALLUVIAL.
Clay
II. MOUNTAIN LIMESTONE.
1. Upper Part of First Limestone
2. Blue Metal
3. Post
4. TOWN-HEAD SEAM
5. White Post
Lamberts lith. Newcastle

Fig. 1.

HITCHCROFT WHIN DIKE.

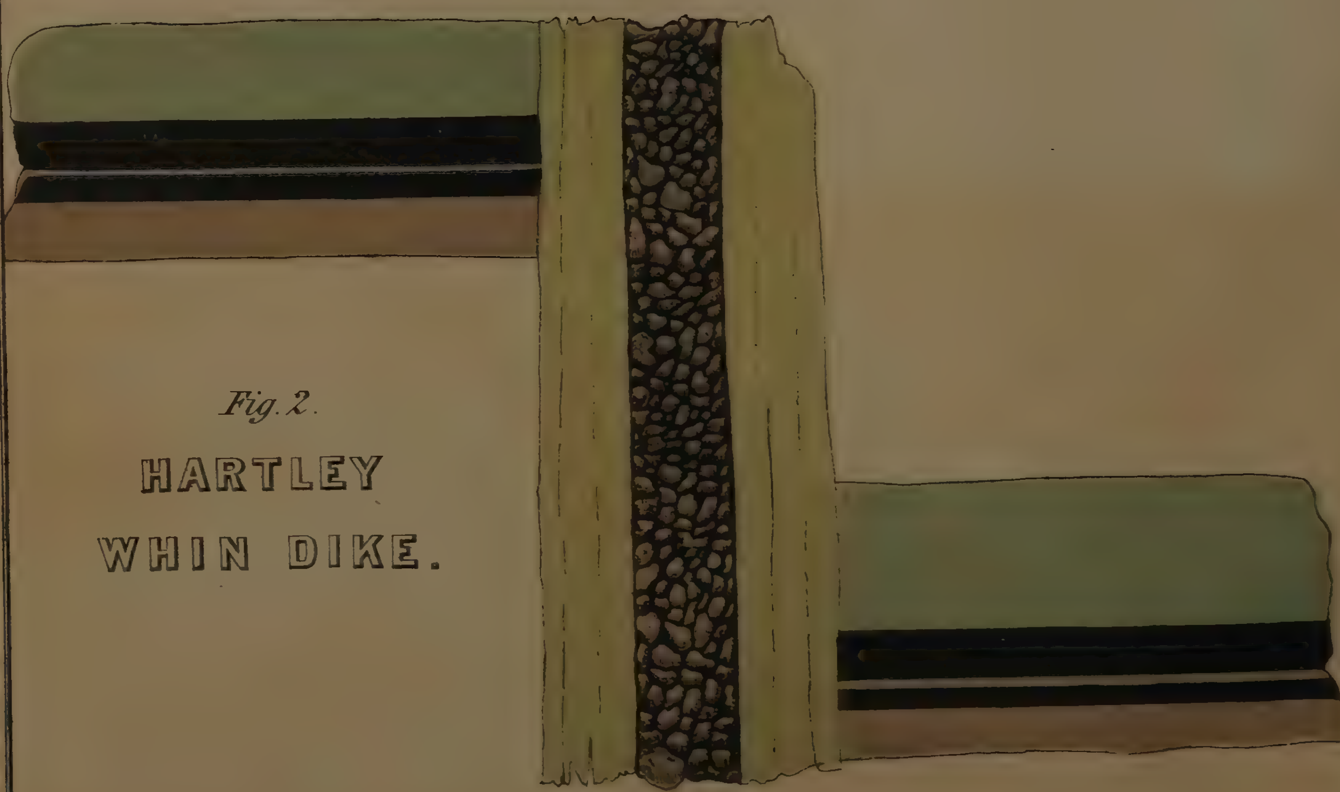


Fig. 2.

HARTLEY

WHIN DIKE.

COALEY HILL DIKE.

Fig. 3

BENWELL COLLIERY.

Fig. 4

SPITAL TONGUES COLLIERY.

SECTIONS

Fig. 1

TYNEMOUTH WHIN DIKE.

Whin or Trap — *Magnesian Limestone* — *Lower New Red Sandstone*

G. C. Greenwell del.

OF STRATA.

COCKFIELD WHIN DIKE.

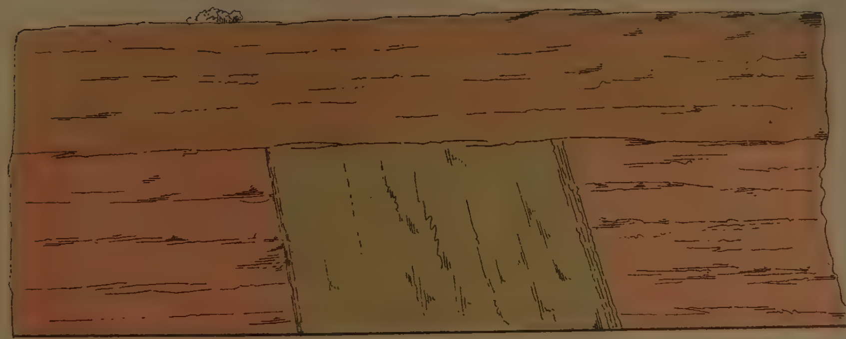


Fig. 2 PRESTON QUARRY.

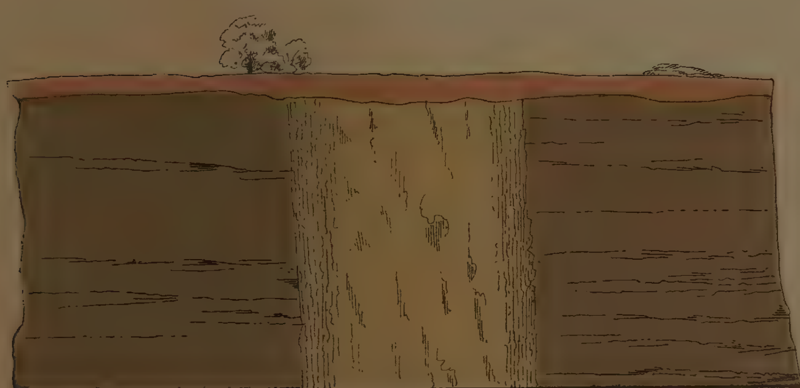


Fig. 3 LANGBARCH QUARRY.

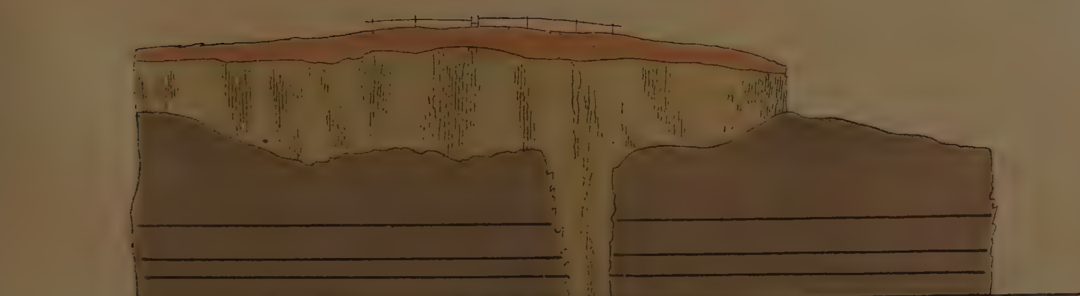


Fig. 4 BOLAM QUARRY.

Upper New Red Sandstone | *Lias* | *Coal Measures*

Lamberts lith Newcastle

SECTIONS

Fig. 1.

BASALTIC DIKE,

AYRSHIRE.

From "Dunn on the Working of Collieries."

G. C. Greenwell del.

F STRATA.

Fig. 2.

GREEN ROCK OR BASALT,

SECTION OF THE DUDLEY PORT "TROUGH FAULT."

From "Transactions of the Manchester Geological Society." Vol: 7

SECTIONS

HORIZO

0 10 20 30 40

VERTI

0 5 10 20 30

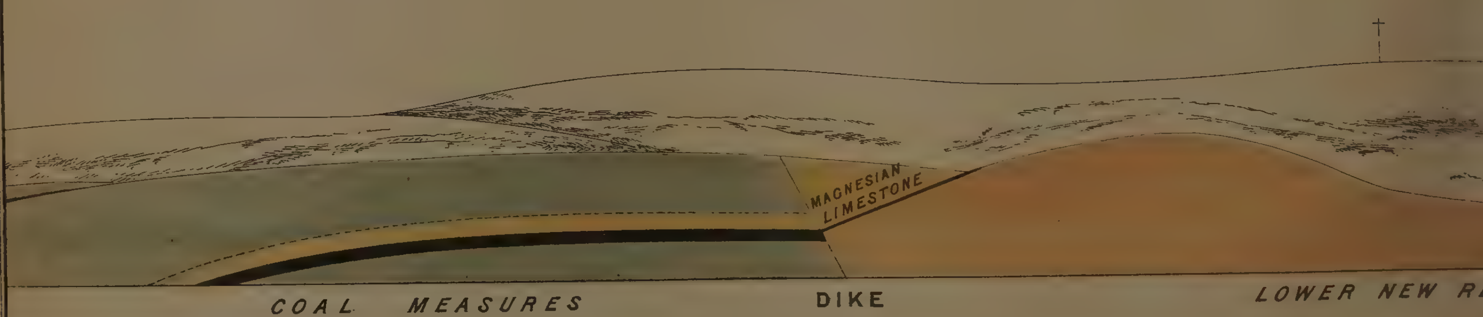
POSITION OF STRATA

OF

90 FATHOM DIKE

AS SEE

CLIFF AT C



The probable Throw of

Dip of Limestone to

" " Red Sandston

" " Coal Measure

Underlay of Fault

G. C. Greenwell del.

OF STRATA.

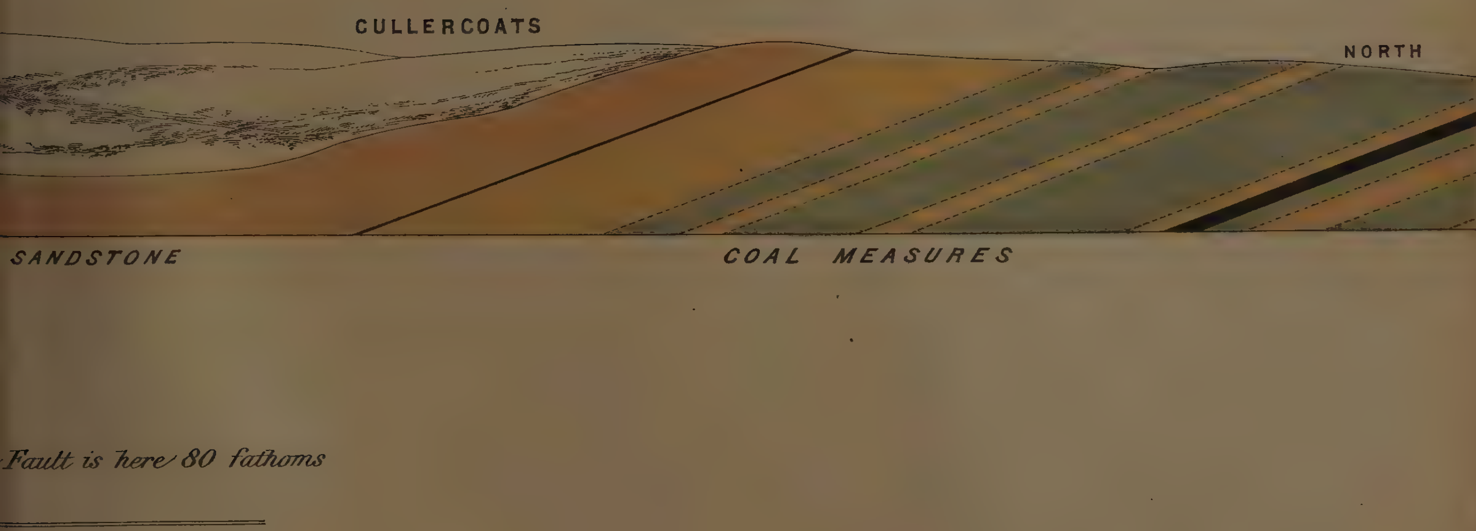
L SCALE

60 70 80 90 100 Yards

SCALE

50 60 70 80 Feet

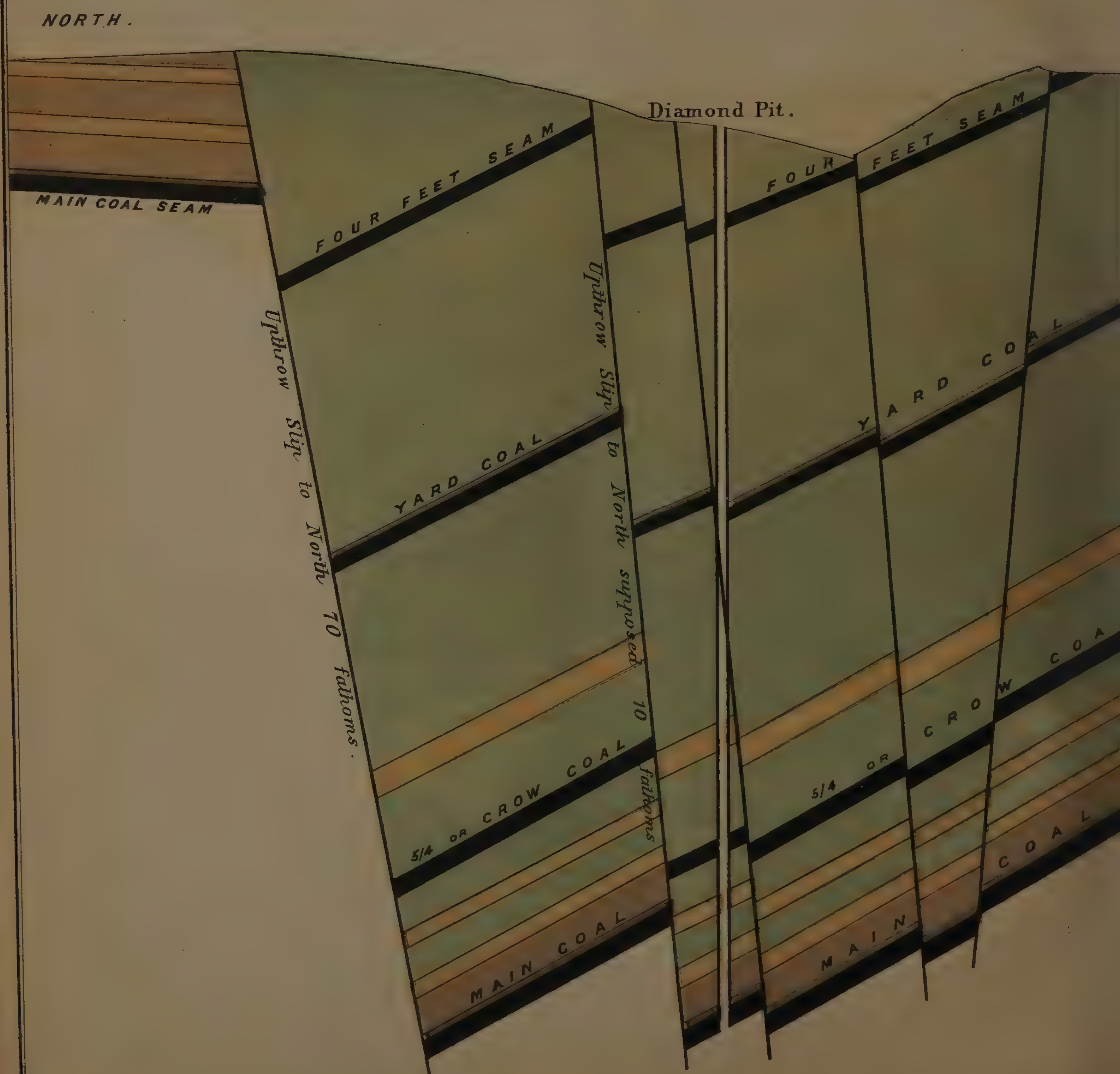
ON OPPOSITE SIDES
HE
R TYNEDALE FAULT,
ON THE
LLERCOATS.



Fault is here 80 fathoms

lt. . 27° near Slip
o . . 27° do
. . 20° 200 yds No. of Slip
. . . 45°

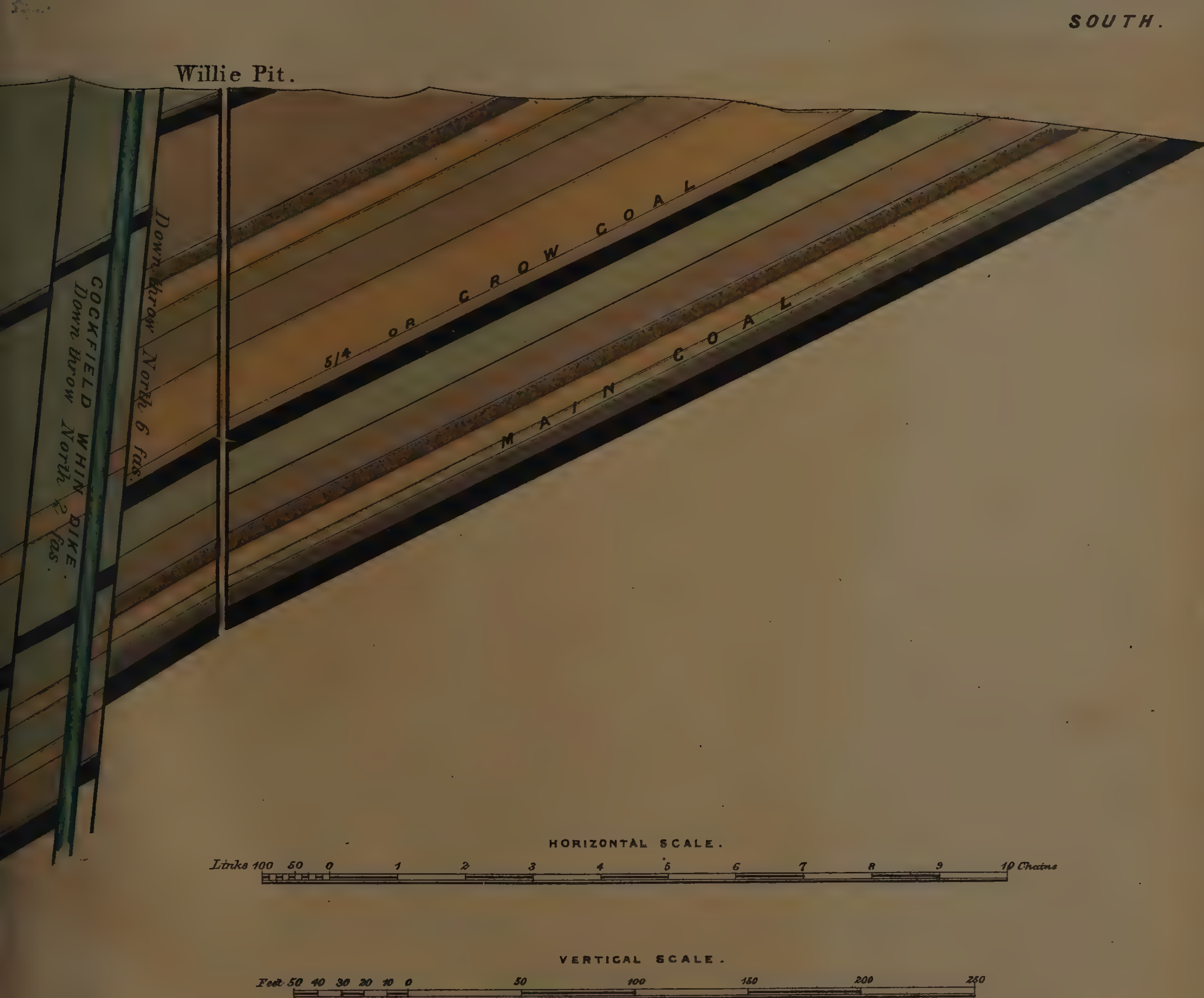
SECTION OF STRATA ACROSS THE AUCKLAND 7
A
BUTTERKNOWLE C



G.C.Greenwell, del.

FATHOM SLIP, AND COCKFIELD WHIN DIKE.

LLIERY, DURHAM.



Lamberts, Lith., Newcastle.

SECTION OF AN OVERLAP FAULT IN THE BULL-VEIN
AT
RADSTOCK COLLIERY.

SCALE.

Inches 12 6 0 1 2 3 4 5 6 7 8 9 10 Feet

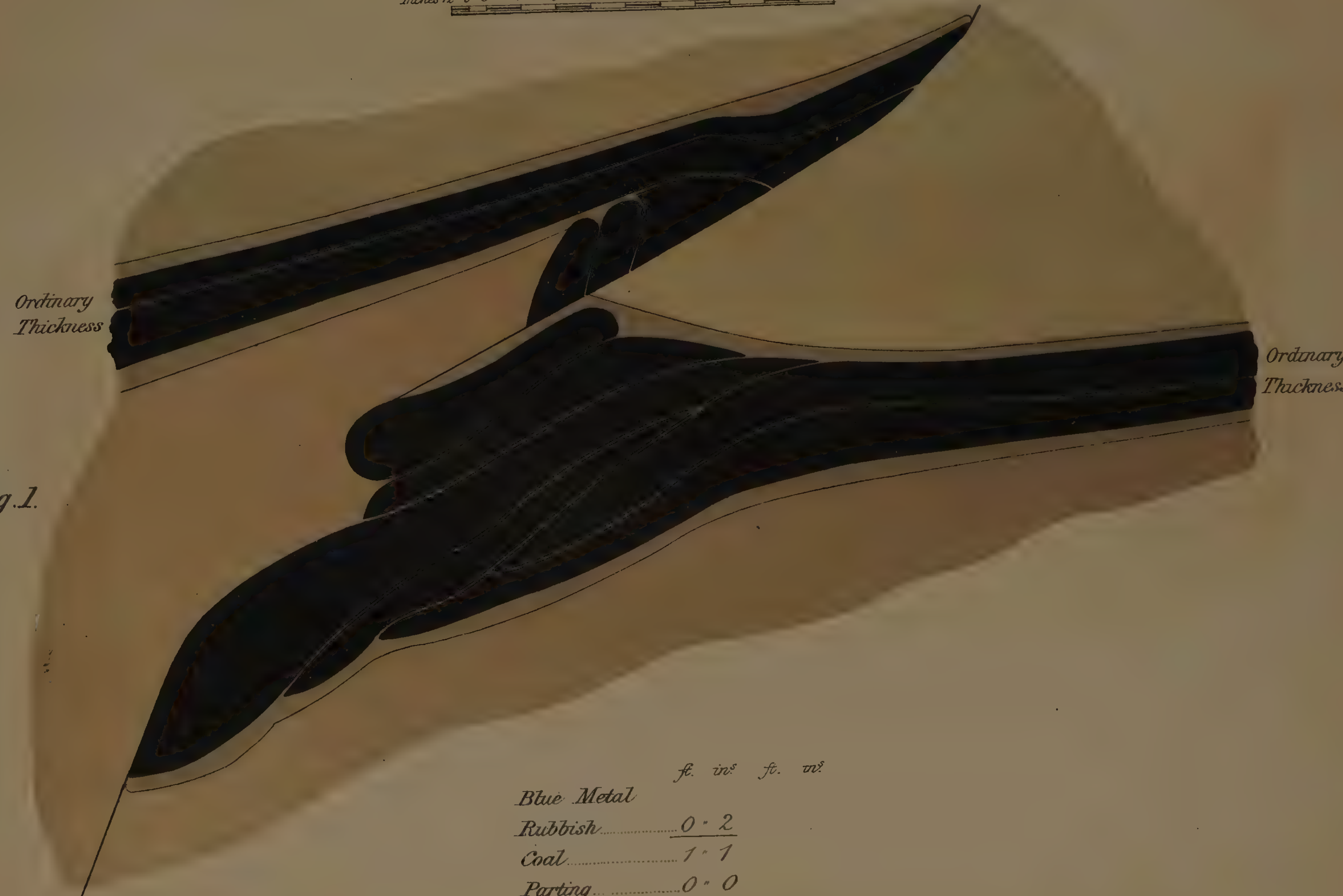


Fig. 1.

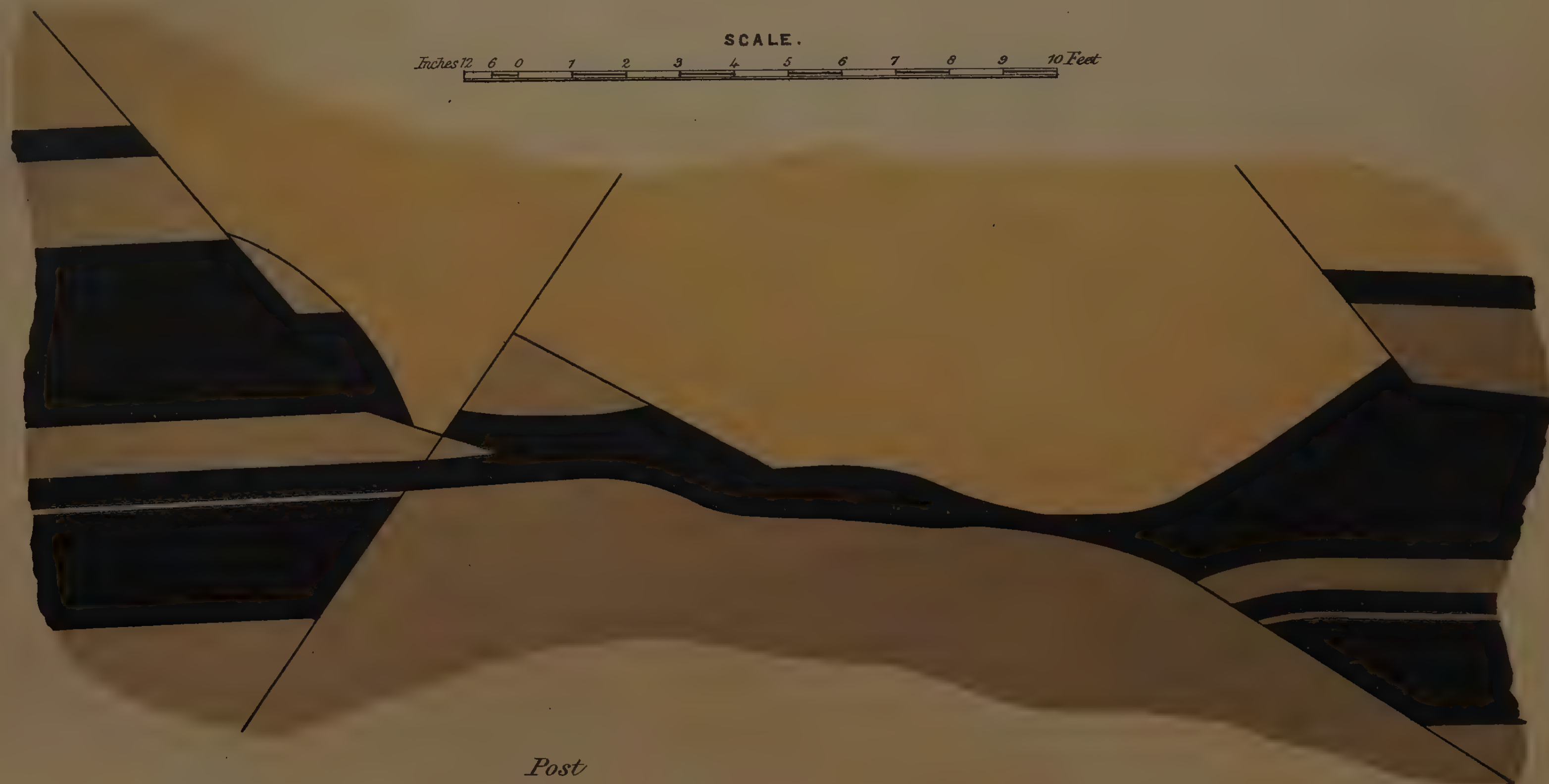
	ft. ins.	ft. ins.
Blue Metal		
Rubbish	0 · 2	
Coal	1 · 1	
Parting	0 · 0	
Coal	1 · 3½	2 · 4½
Black Metal		

SECTION OF A BALK IN THE BUSTYBANK SEAM
AT
BURNOPFIELD COLLIERY.

SCALE.

Inches 12 6 0 1 2 3 4 5 6 7 8 9 10 Feet

Fig. 2.



			ft. in.	ft. in.
Post				
Coal				
Grey Thill				
Coal		Bustybank Seam	3 · 4	
Fireclay good			0 · 11½	
Coal			0 · 6½	
Blackstone			0 · 0¾	
Coal			2 · 2¾	7 · 1½
Fireclay good				

BORING

Fig. 3 a

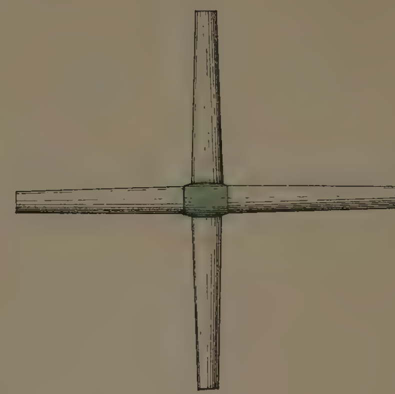


Fig. 3 c

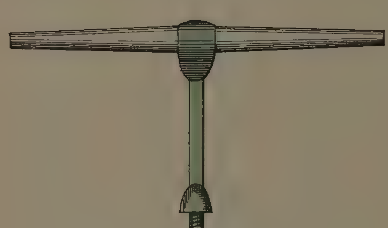


Fig. 3 b

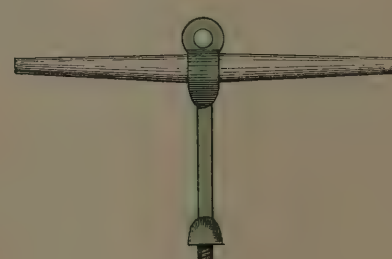
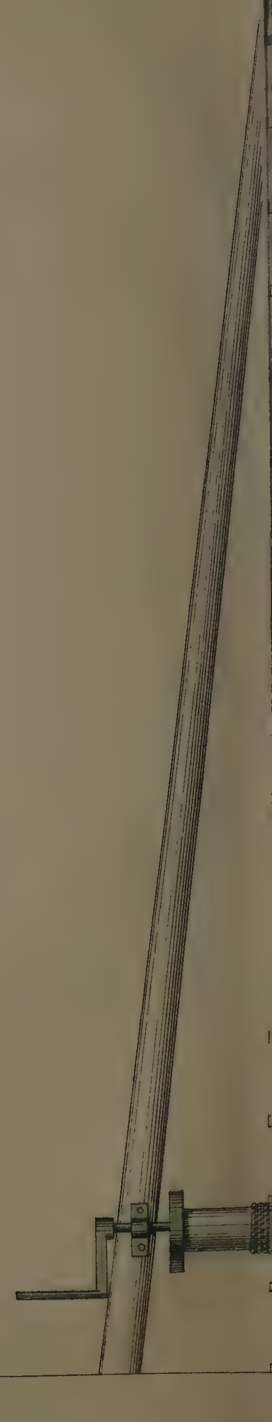


Fig. 3 .d

Fig. 12

Fig. 2



Scale of Figs. 1 & 2.

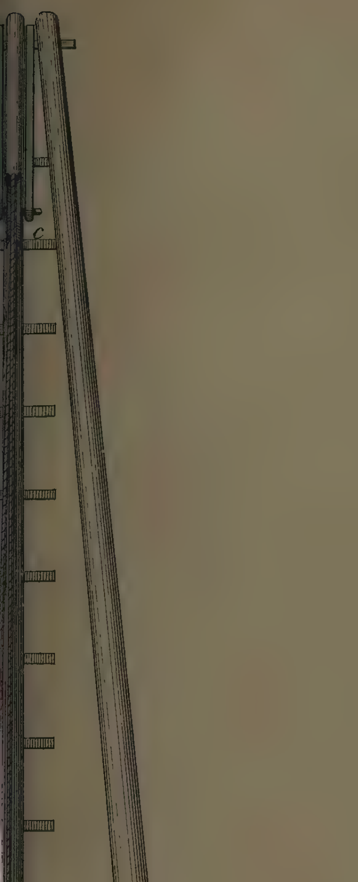
0 1 2 3 4 5 6 7 8 9 10 Feet

Scale of Figs. 3 to 12

0 1 2 3 4 5 Feet

G. C. Greenwell del.

PPARATUS



g.1

Fig.4

Fig.5

Fig. 6.

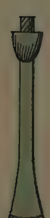


Fig.7

Fig.8

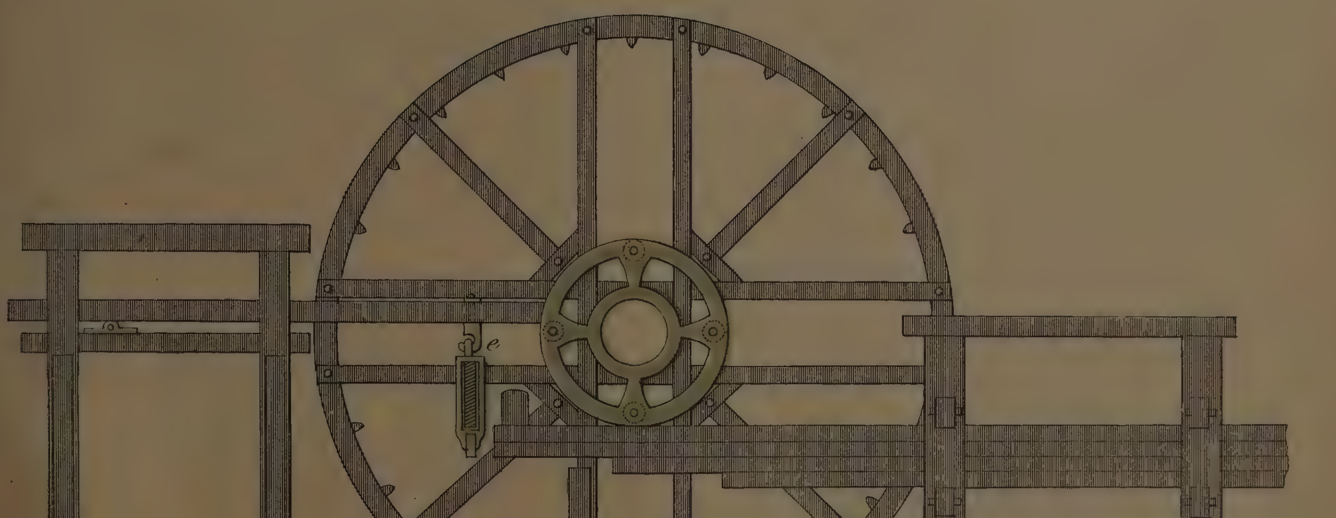
Fig.9

Fig.10

Fig. 11

Lamberts lith Newcastle

PLAN
OF
KIND'S BORING MACHINE.



From Combes' Traité de l'exploitation.

G. C. Greenwell del.

Lamberts lith. Newcastle.

SECTION

SHEWING THE EXPECTED & ACTUAL POSITION OF THE

SEAMS OF COAL,

AS PROVED BY BORING & SINKING AT

CORNFORTH COLLIERY.

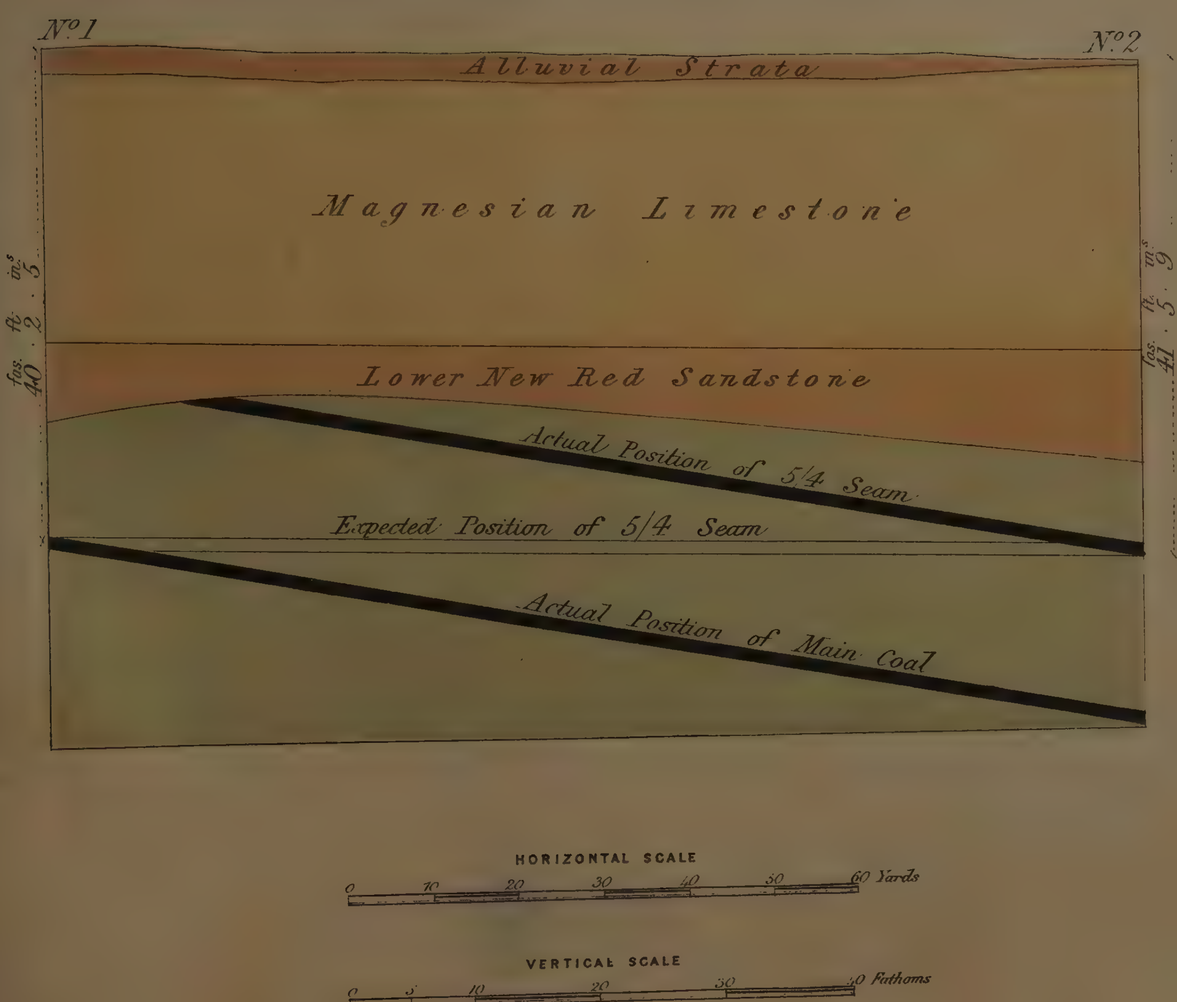


Fig. 1.

G. C. Greenwell del.

M S.

Fig. 2.

END VIEW

FRONT VIEW

SCALE OF FEET.

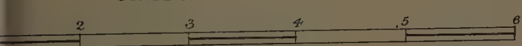
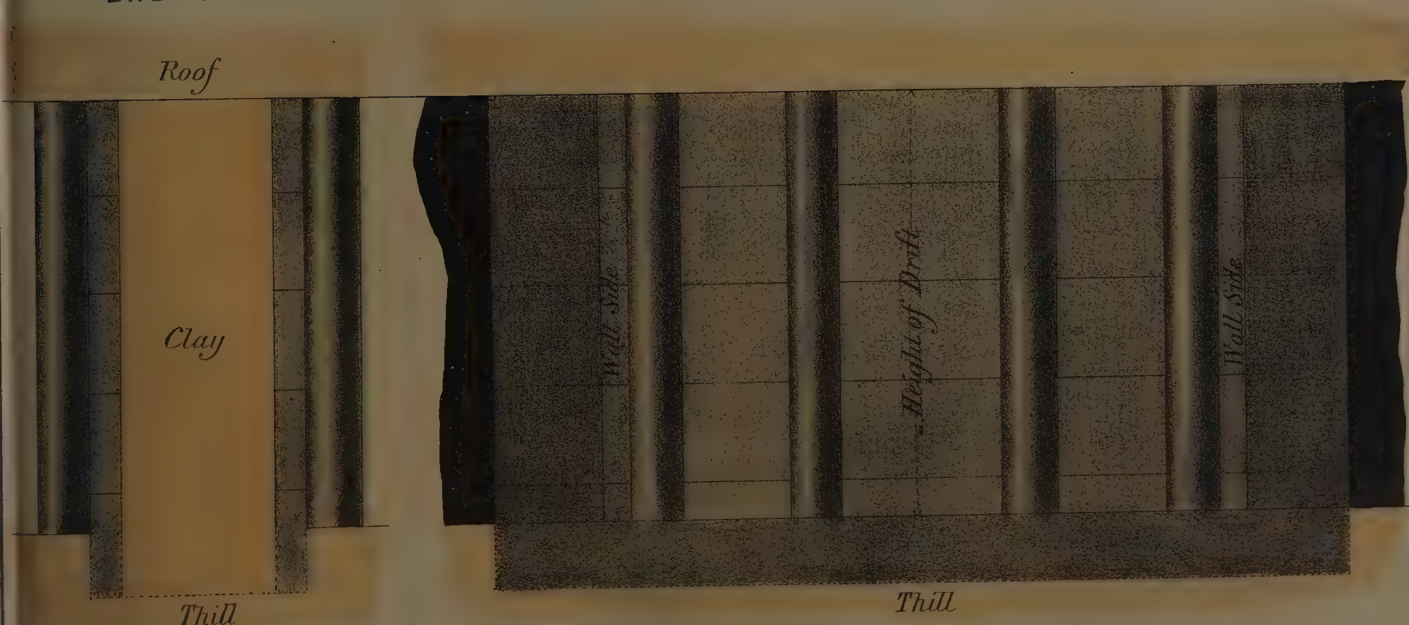


Fig. 3.

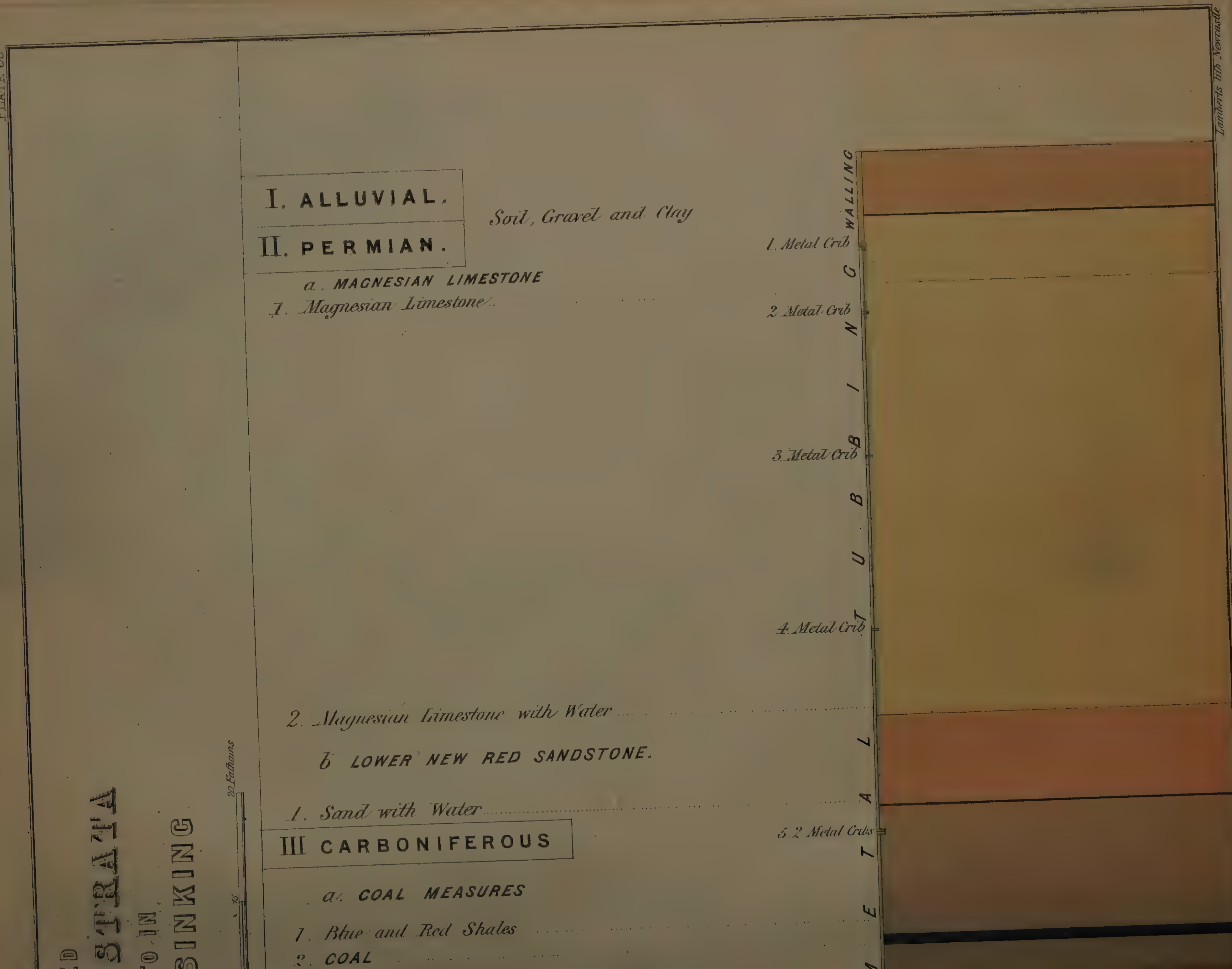
END VIEW

FRONT VIEW



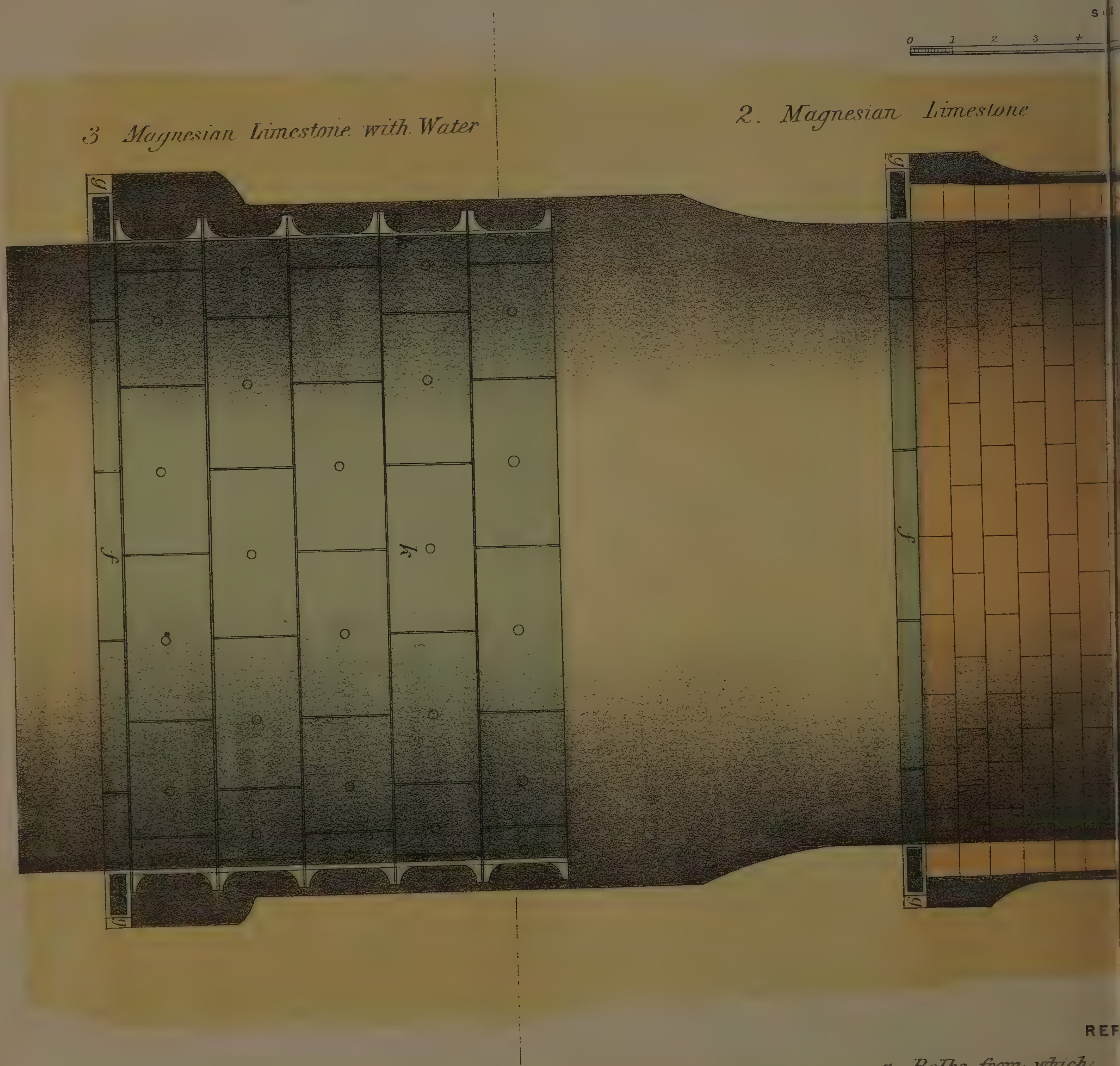
SECTION
ACCOUNT
3. Grey Shale or Metal
4. Rock or Post
5. Blue Shale or Metal
6. Black Shale or Metal
7. Rock or Post
8 COAL
6 Metal Crib
1. Oak Crib
2 Oak Crib
3 Oak Crib
4 Oak Crib
W A L L I N G

PLATE 35


D
STRATA
O IN
SINKING
15
20 Fathoms
I. ALLUVIAL.
Soil, Gravel and Clay
II. PERMIAN.
a. MAGNESIAN LIMESTONE
1. Magnesian Limestone
2. Magnesian Limestone with Water
b LOWER NEW RED SANDSTONE.
1. Sand with Water
III CARBONIFEROUS
a. COAL MEASURES
1. Blue and Red Shales
2. COAL
WALLING
1. Metal Crib
2 Metal Crib
3. Metal Crib
4. Metal Crib
5. 2 Metal Cribs
TUBBING
METAL
Lamberts lith Newcastle

SIN

TIMBERING, WALLING



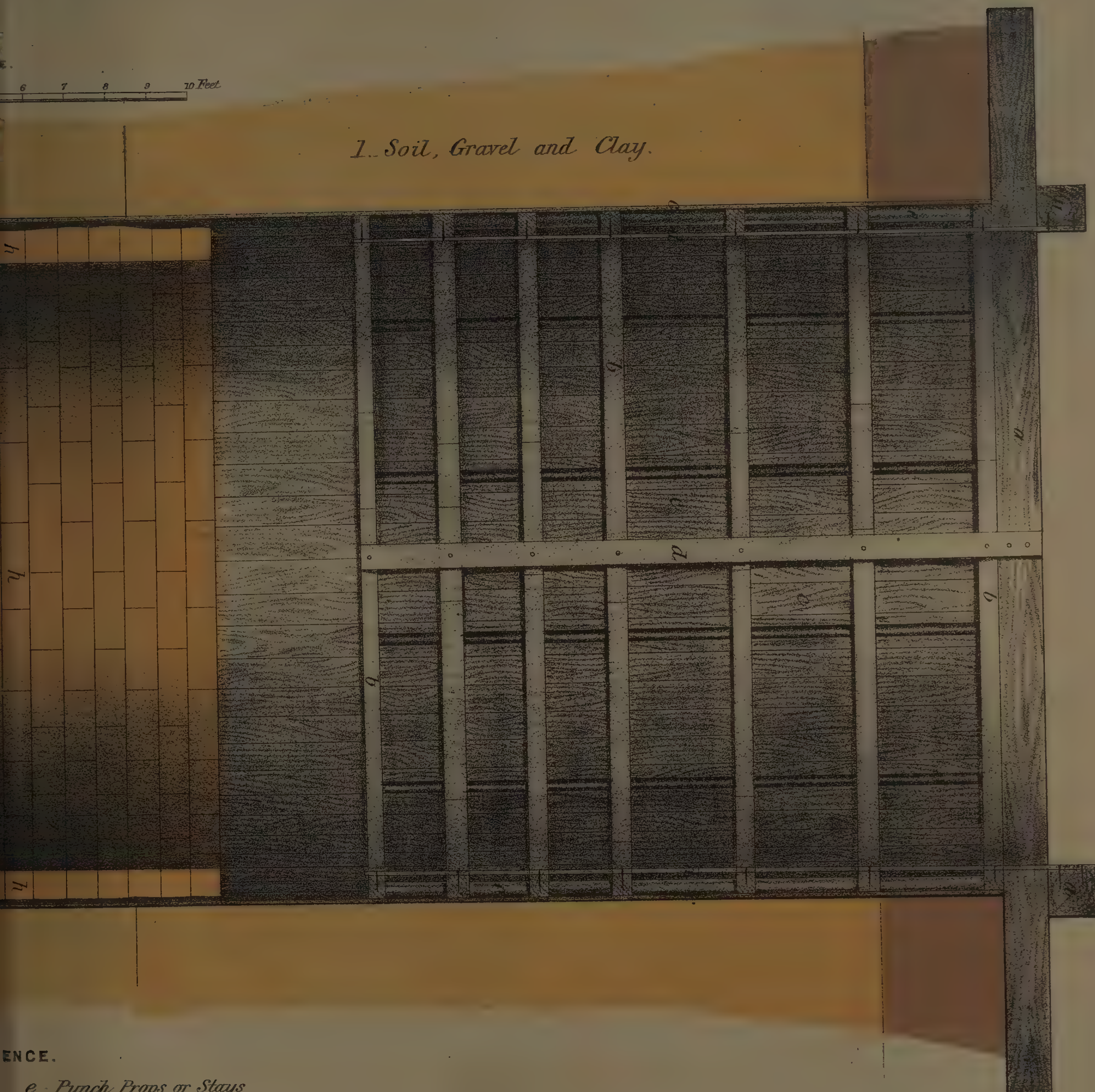
REF

a.. Balks from which to hang Timber
b.. Cribs
c.. Backing Deals
d.. Stringing Planks

G.C.Greenwell del.

NG,

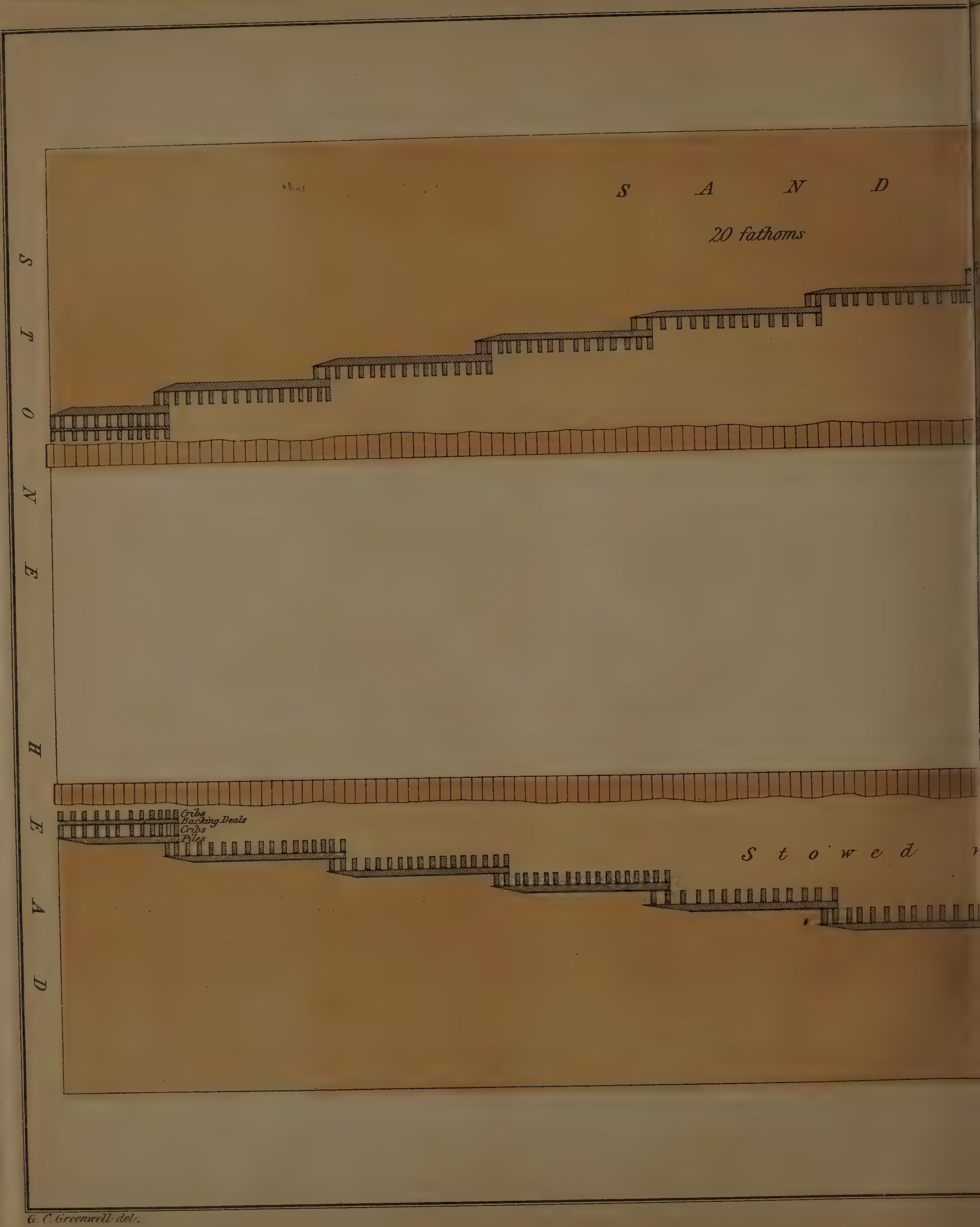
ND METAL TUBBING.



ENCE.

e. Punch Props or Stays
f. Wedging Cribs, metal.
g. Packing and Wedging
h. Walling
k. Metal Tubbing

Lamberts lith. Newcastle



G. C. Greenwell del.

SECTION
OF
FRAMWELLGATE MOOR PIT TO THE STONE HEAD.

PILES 6 × 3 Inches

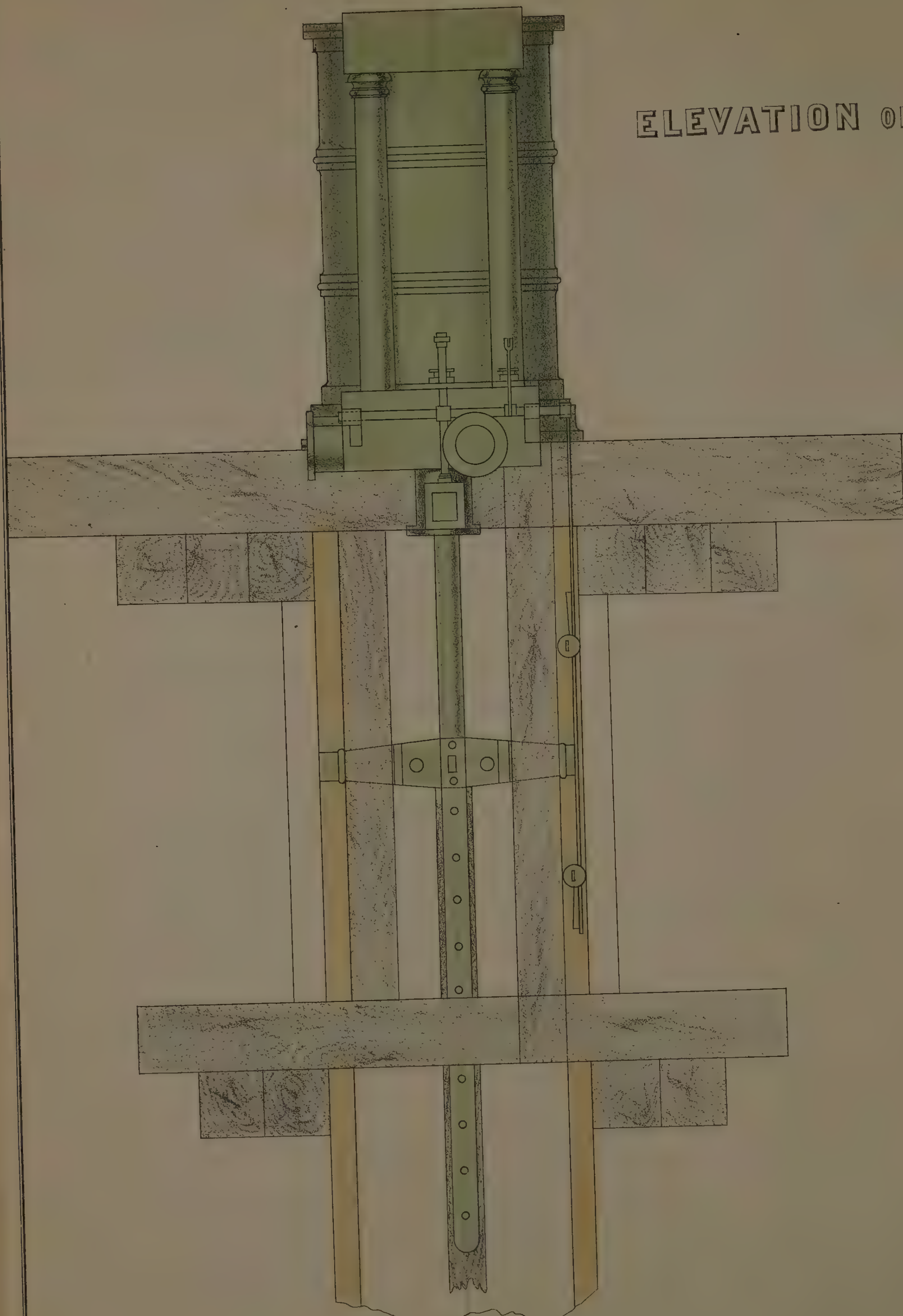
CRIBS 6 × 6 Inches

Lamberts lith Newcastle

ELEVATION OF A DIRECT-A

FOR PUM

Diameter of
Length of



SCA

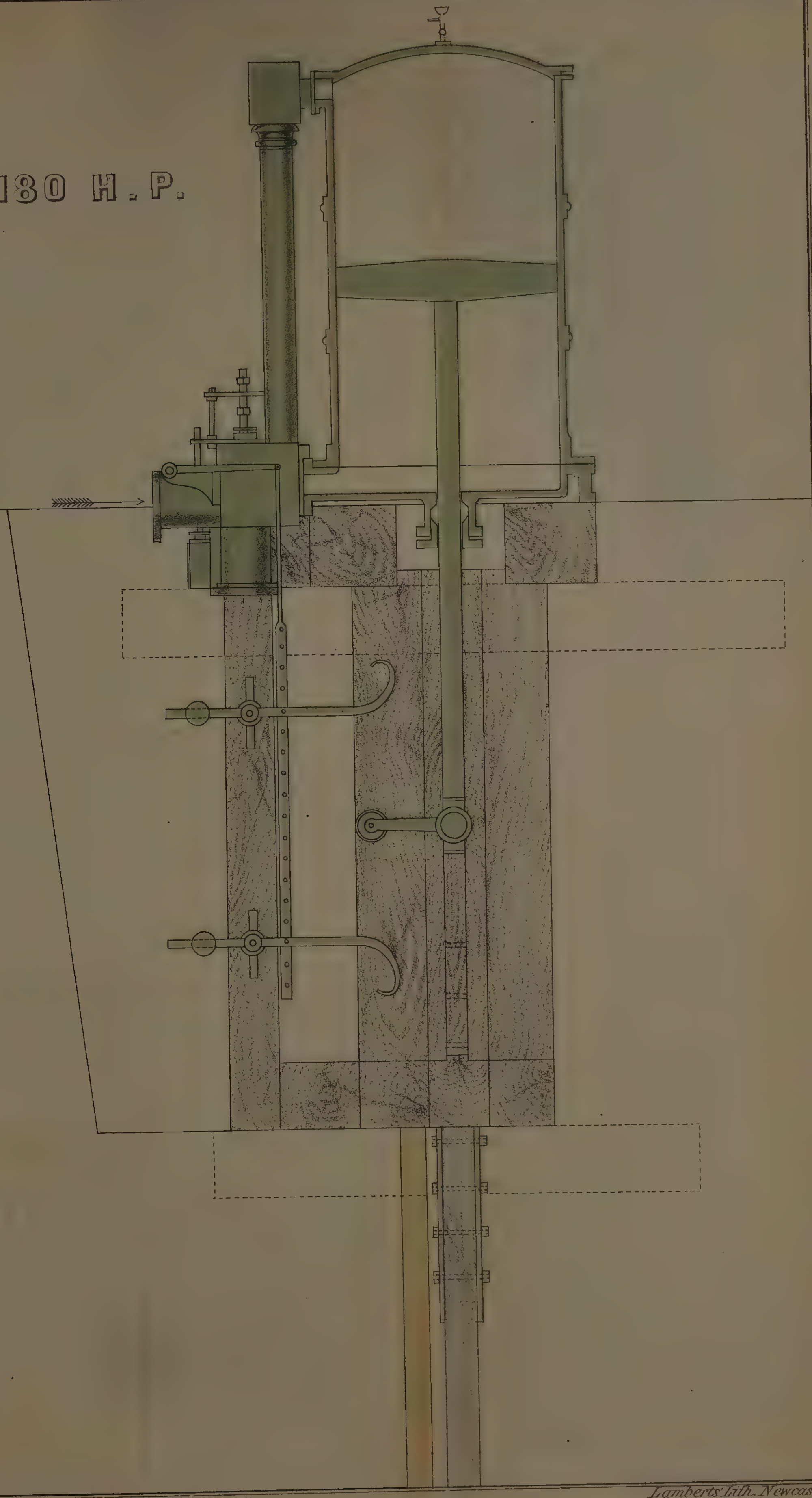
0 1 2 3 4 5

G.C. Greenwell, del

CTING ENGINE OF 180 H.P.

ING WATER.

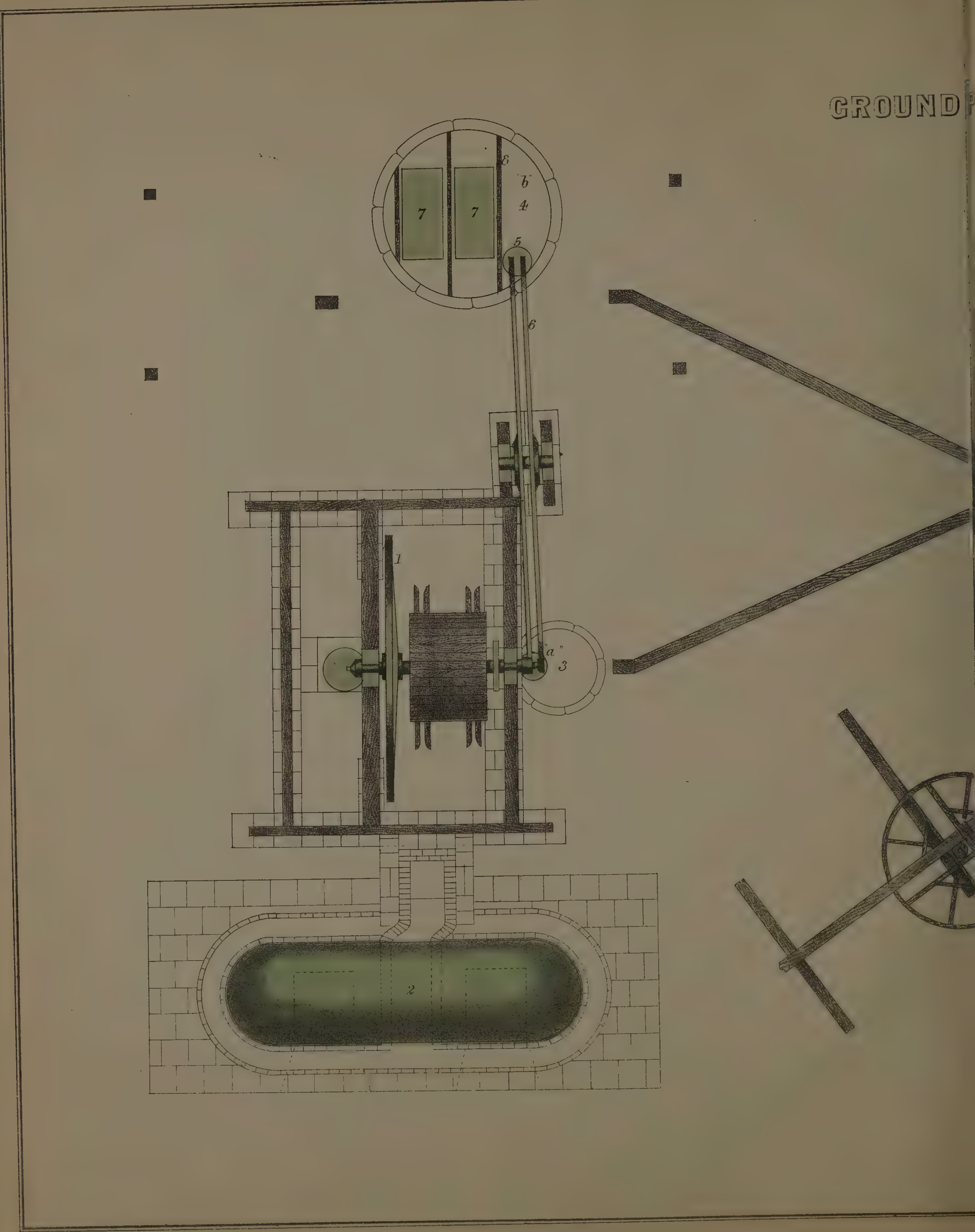
ylinder .. 80 in
oke .....10 ft



E OF FEET.
10 15

Lamberts Lith. Newcastle

GROUND



G. C. Greenwell. del.

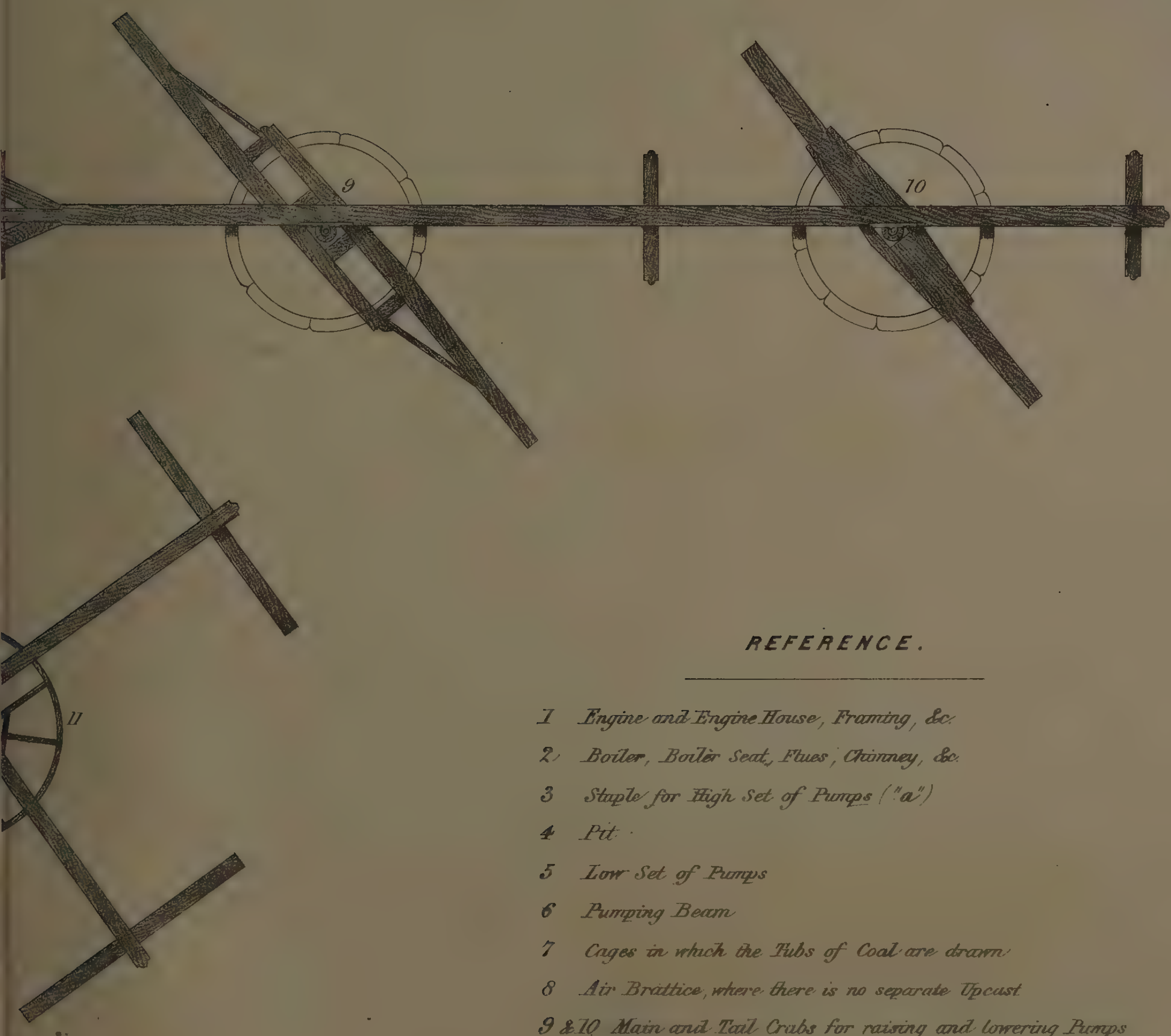
PLAN OF A CONDENSING ENGINE OF 30 H.P.

WITH THE ARRANGEMENTS REQUIRED

FOR DRAWING COALS AND PUMPING WATER.

SCALE

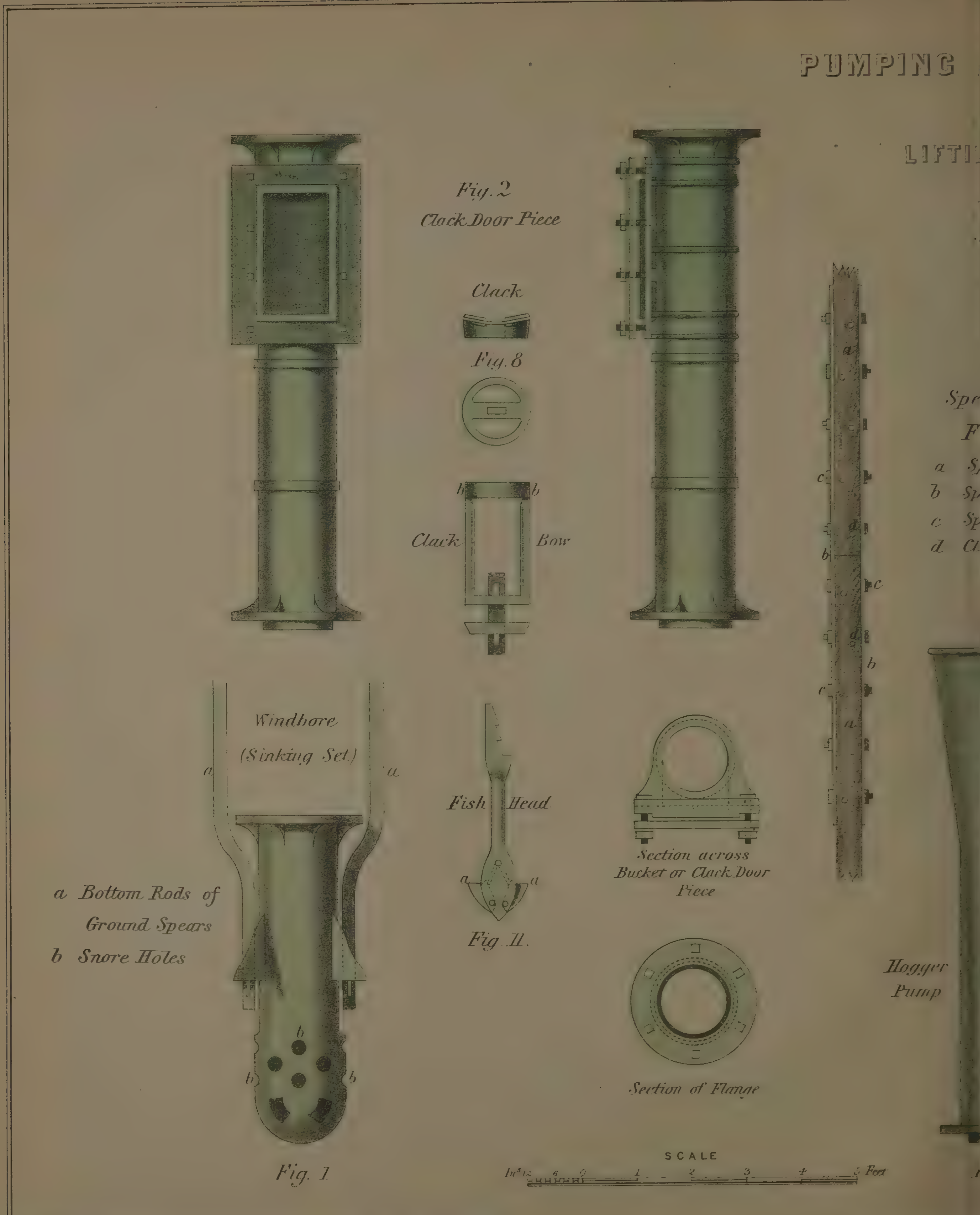
0 1 2 3 4 5 10 15 20 Feet



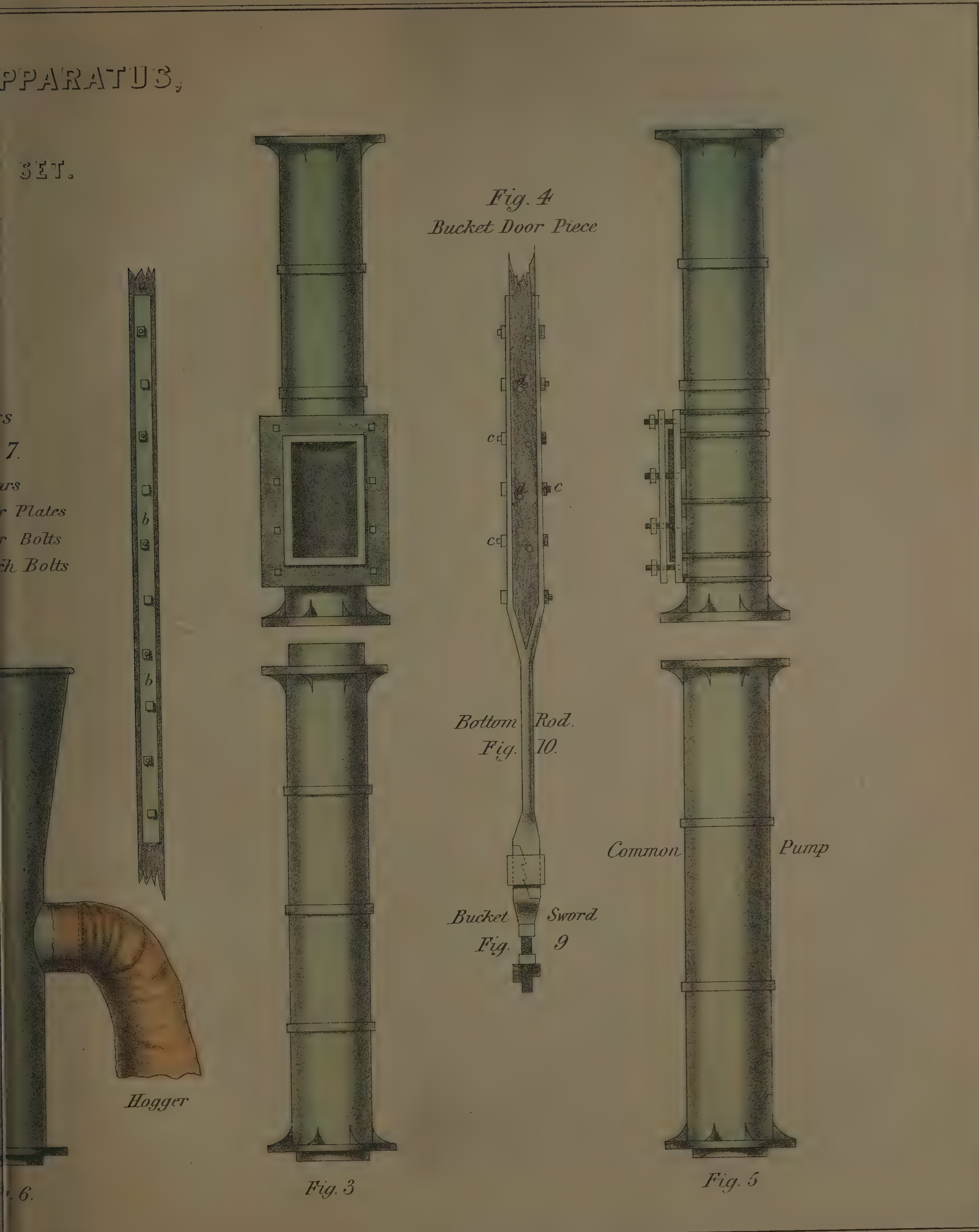
REFERENCE.

1 Engine and Engine House, Framing, &c.
2 Boiler, Boiler Seat, Flues, Chimney, &c.
3 Staple for High Set of Pumps ("a")
4 Pit
5 Low Set of Pumps
6 Pumping Beam
7 Cages in which the Tubs of Coal are drawn
8 Air Brattice, where there is no separate Upcast
9 & 10 Main and Tail Crabs for raising and lowering Pumps
11 Gin for raising and lowering Men in Staple or Back Shaft ("b")

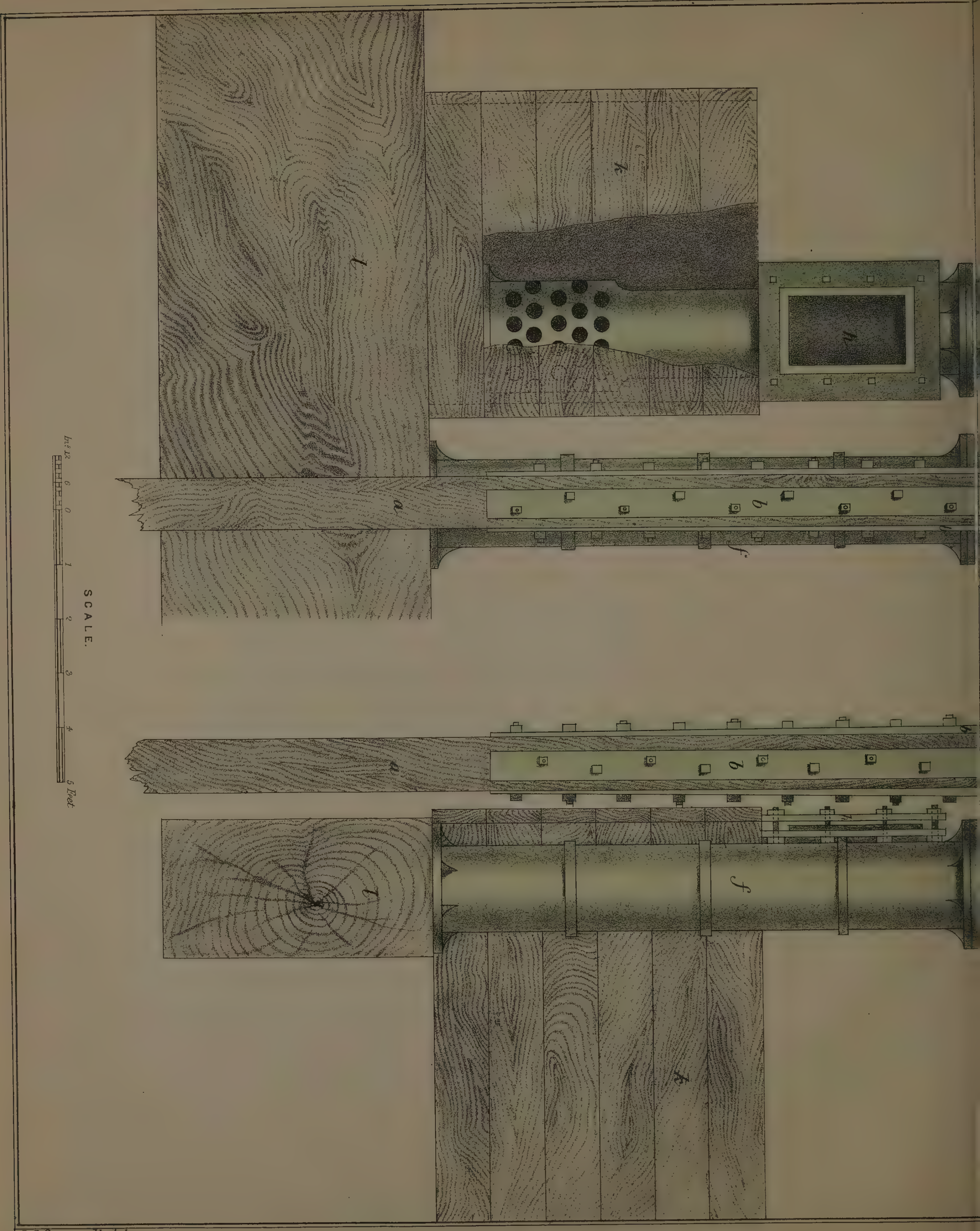
Lamberts Lith Newcastle



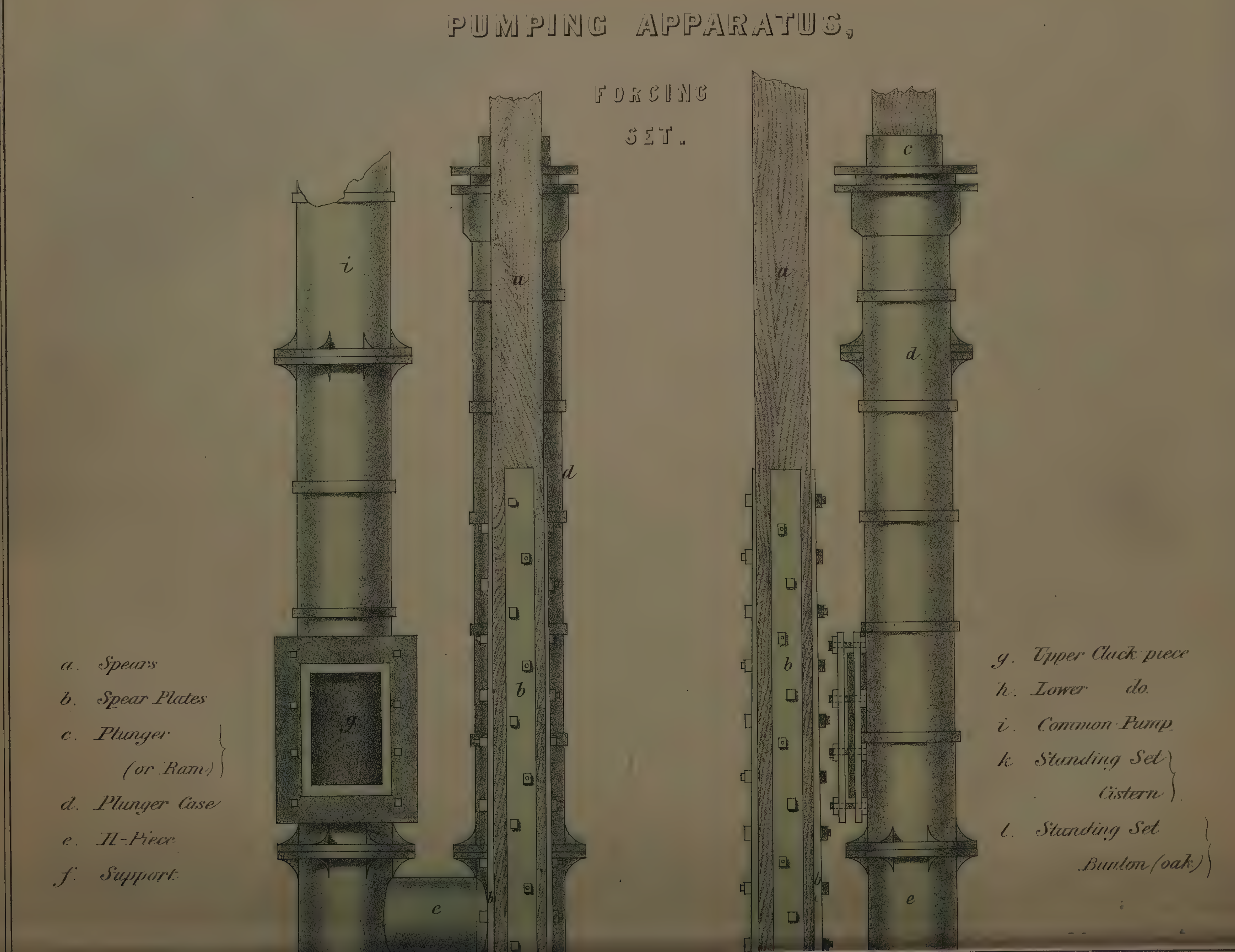
G.C.Greenwell del.



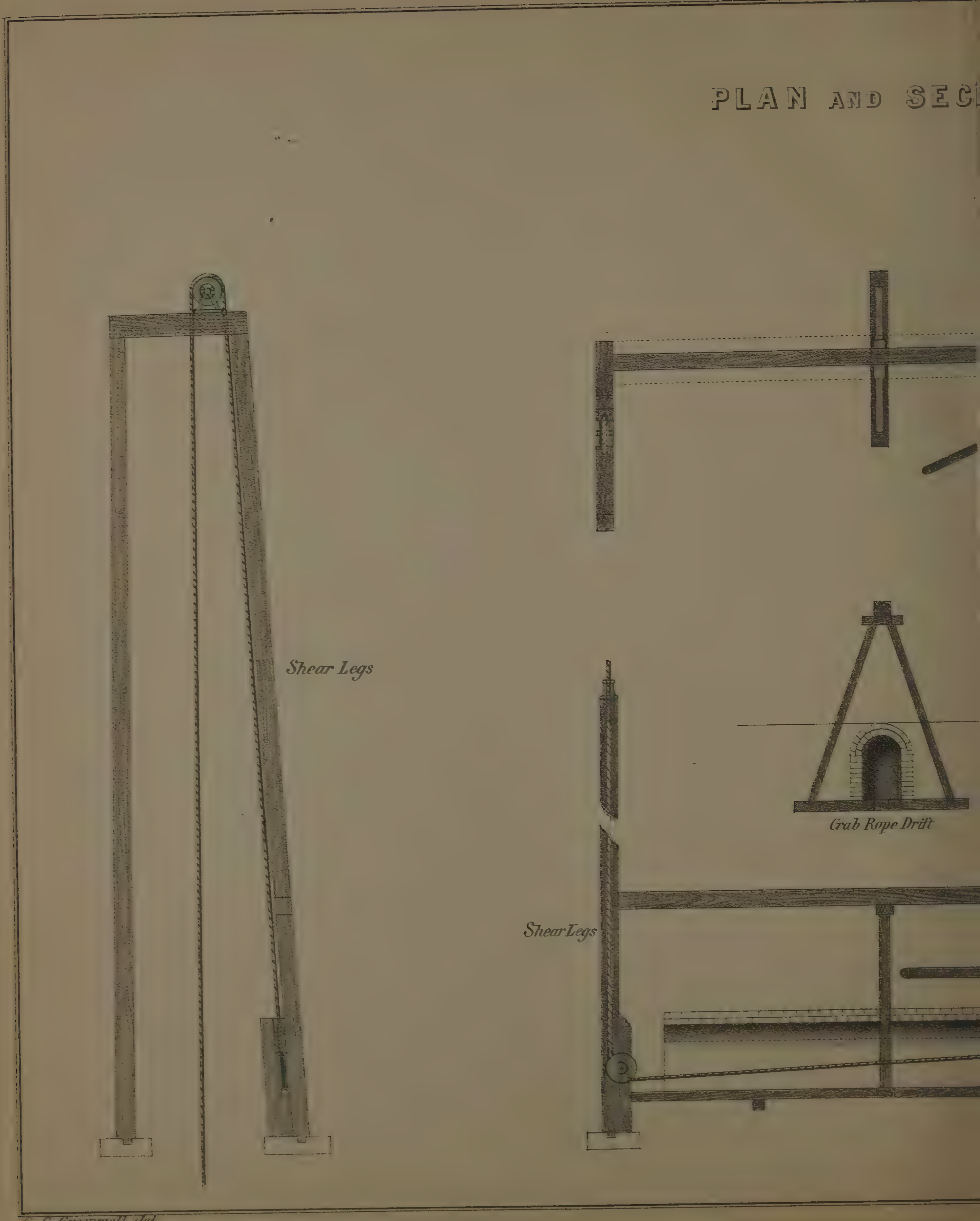
Lamberts lith. Newcastle



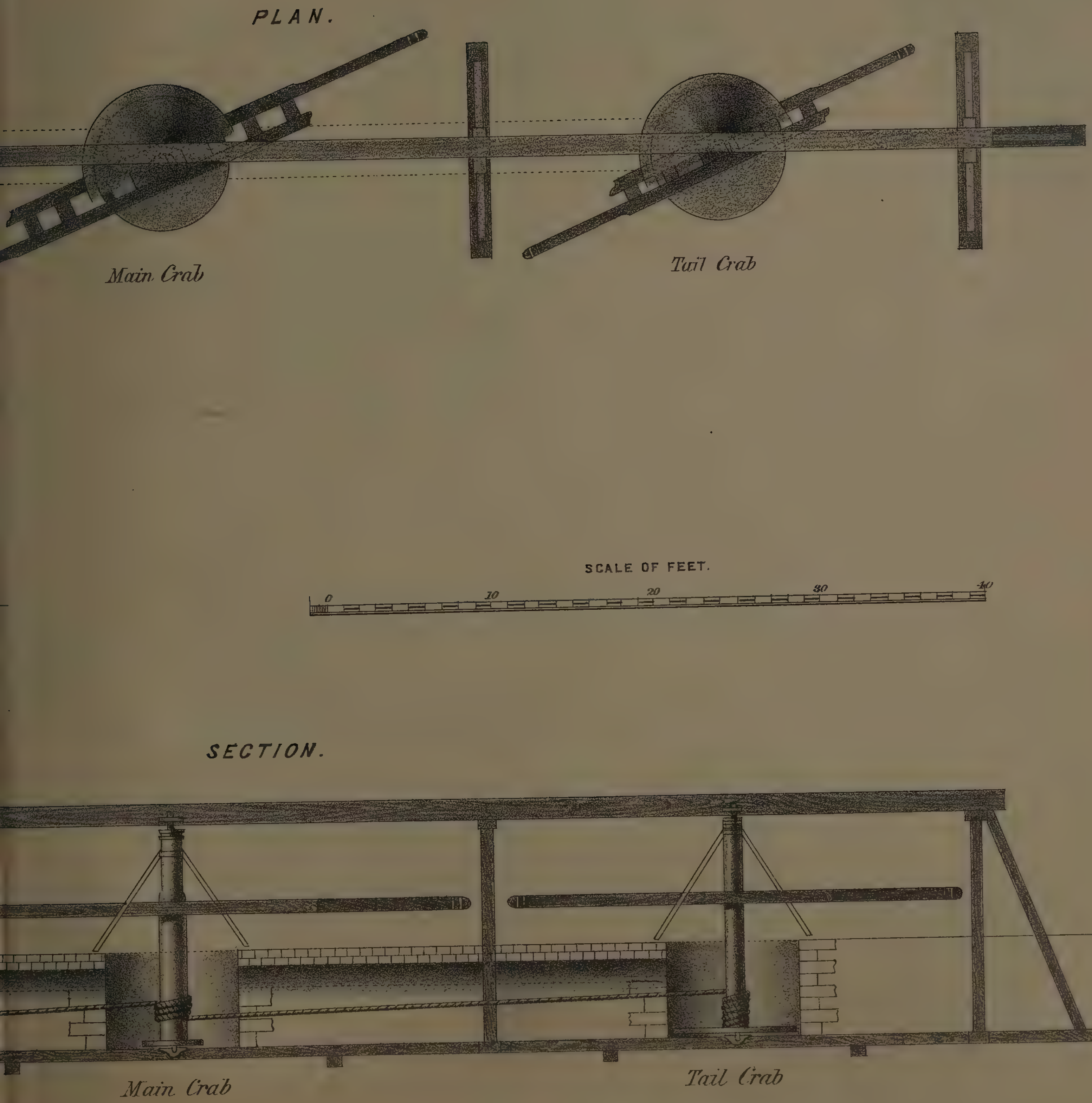
G.C.Greenwell del.



Lamberts lith.s Newcastle


PLAN AND SEC
Shear Legs
Grab Rope Drift
Shear Legs

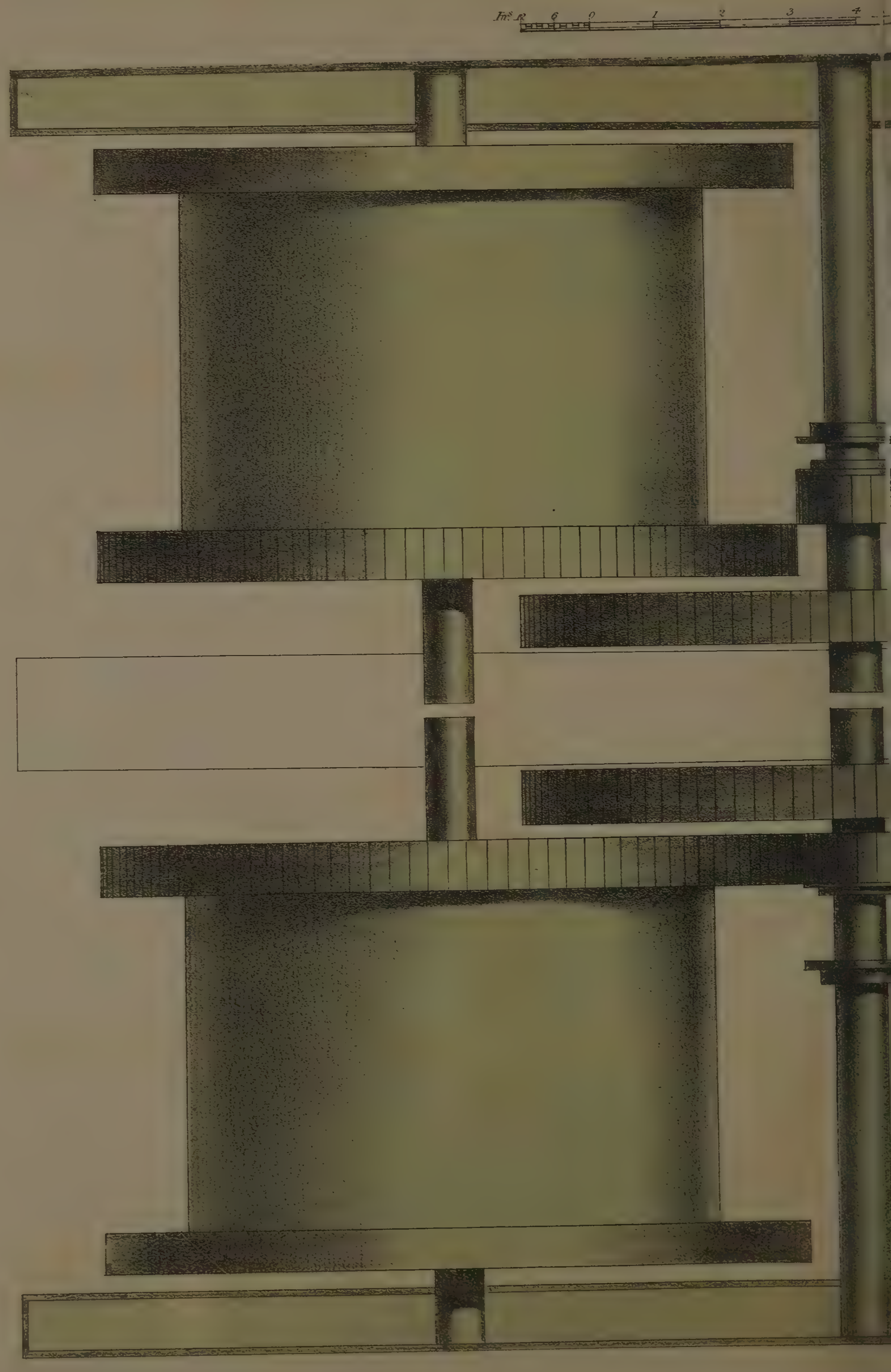
ION OF CRABS.



Lamberts' lith^s Newcastle

PLAN OF STEAM CRAB

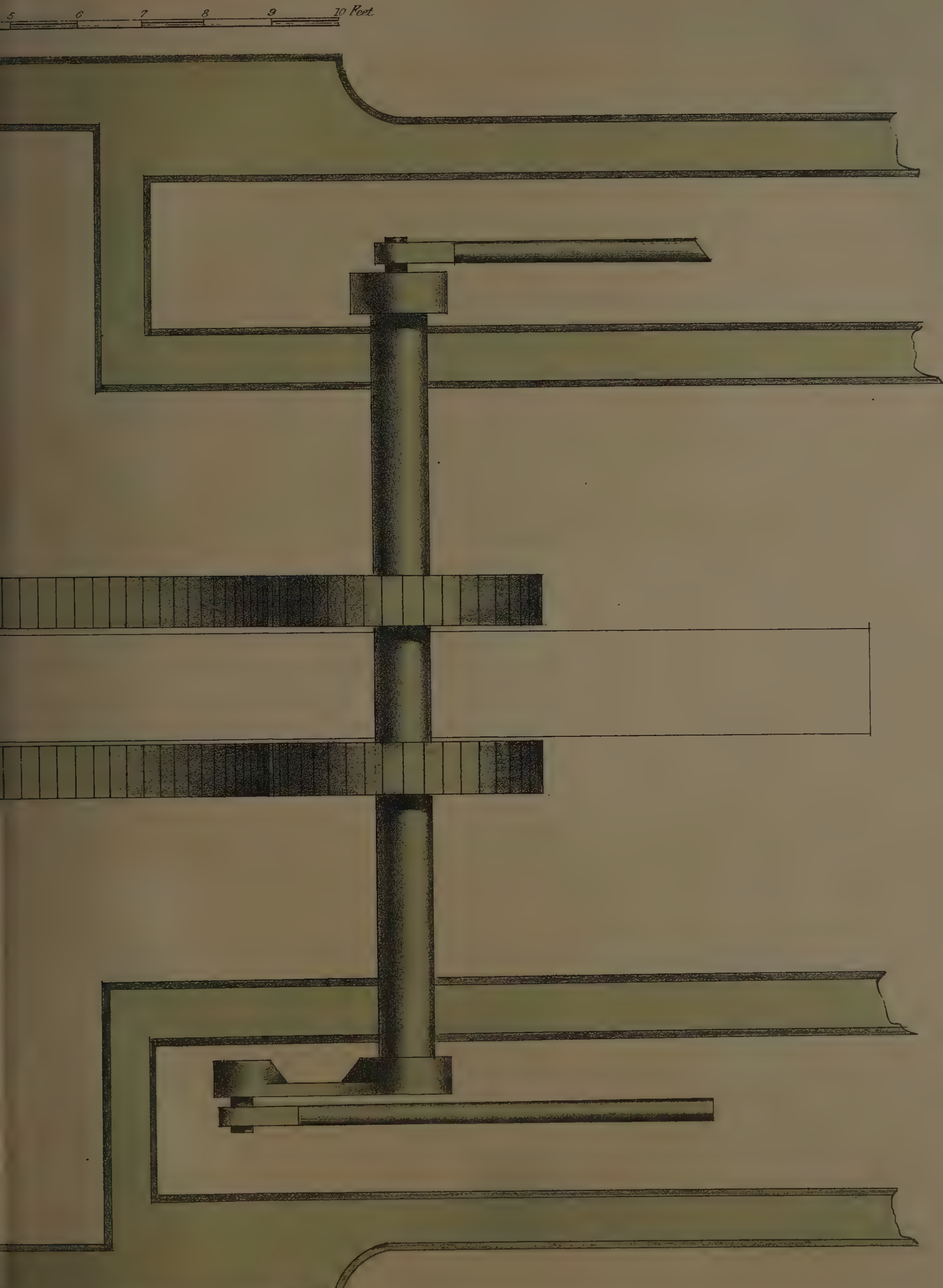
SC



G. F. Greenwell del.

AT WALLSEND COLLIERY.

E.



Lamberts Lith. Newcastle

PLAN
OF COAL OR IRONSTONE WORKING BY
LONG WALL.

Fig. 1

The Arrows shew the course of the Air Currents

Stopping *Door* *Crossing*

Tram or Horse Road coloured Blue

Portion exhausted

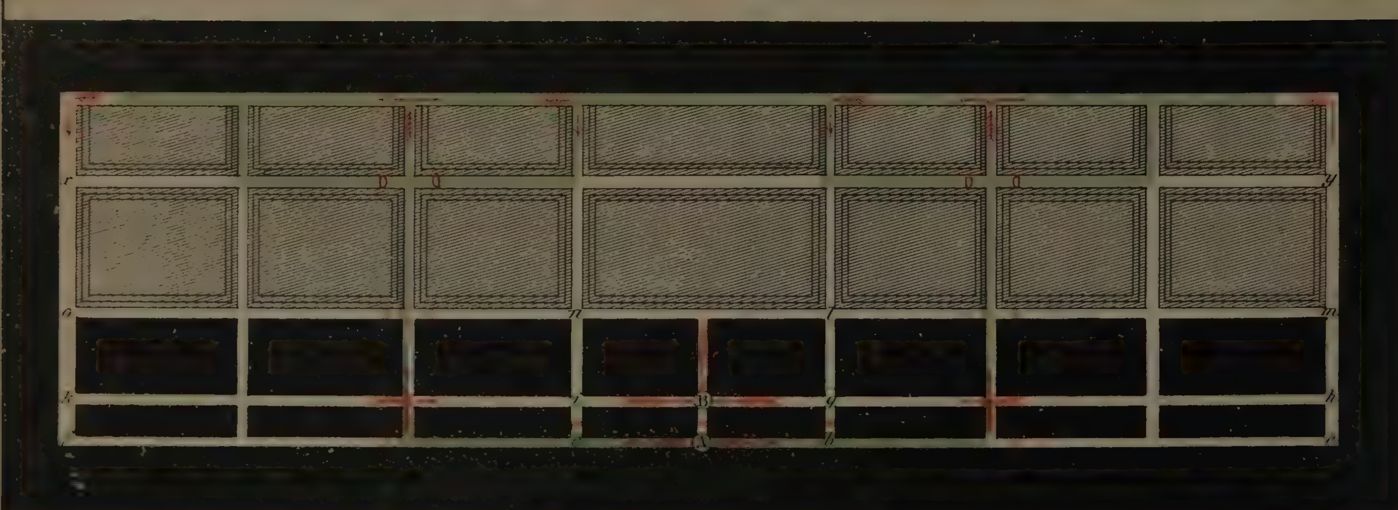


Fig. 2

G. C. Greenwell, del.

PLAN

OF COAL OR IRONSTONE WORKING BY

POST AND STALL.

Fig. 3

Lambert's lith^s. Newcastle

COAL WORKINGS.

SHAFT PILLARS AND WATERLEVEL DRIFTS.

Fig. 1

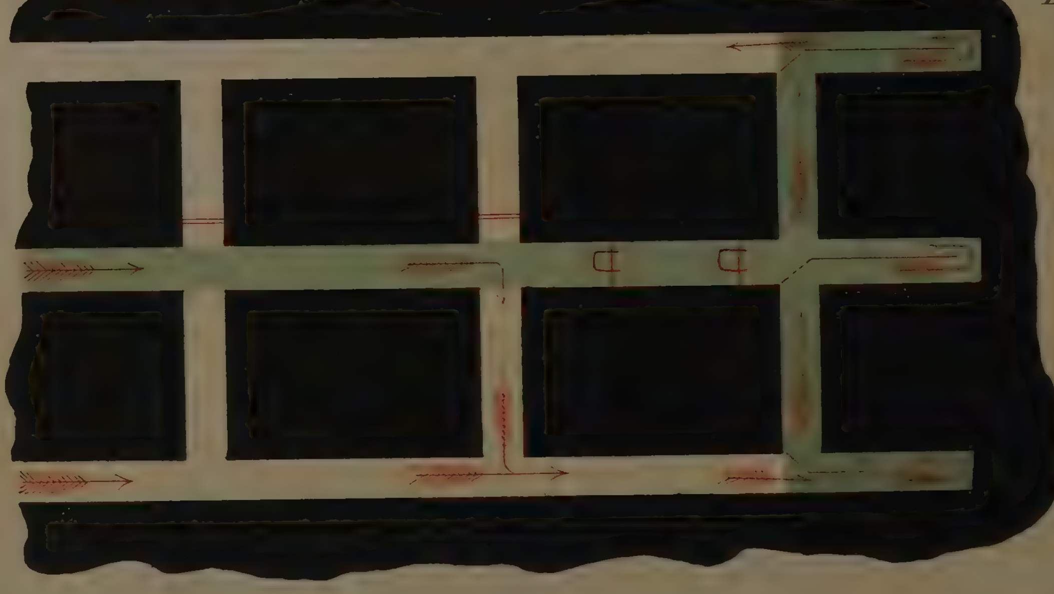


Fig. 2

G. C. Greenwell del.

Fig. 3

COAL WORKINGS.

FIG. 3. Waterlevel Course Parallel with the direction of the Cleavage of the Coal

FIG. 4. Waterlevel Course at Right Angles with the direction of the Cleavage

Fig. 4

Lamberts lith. Newcastle

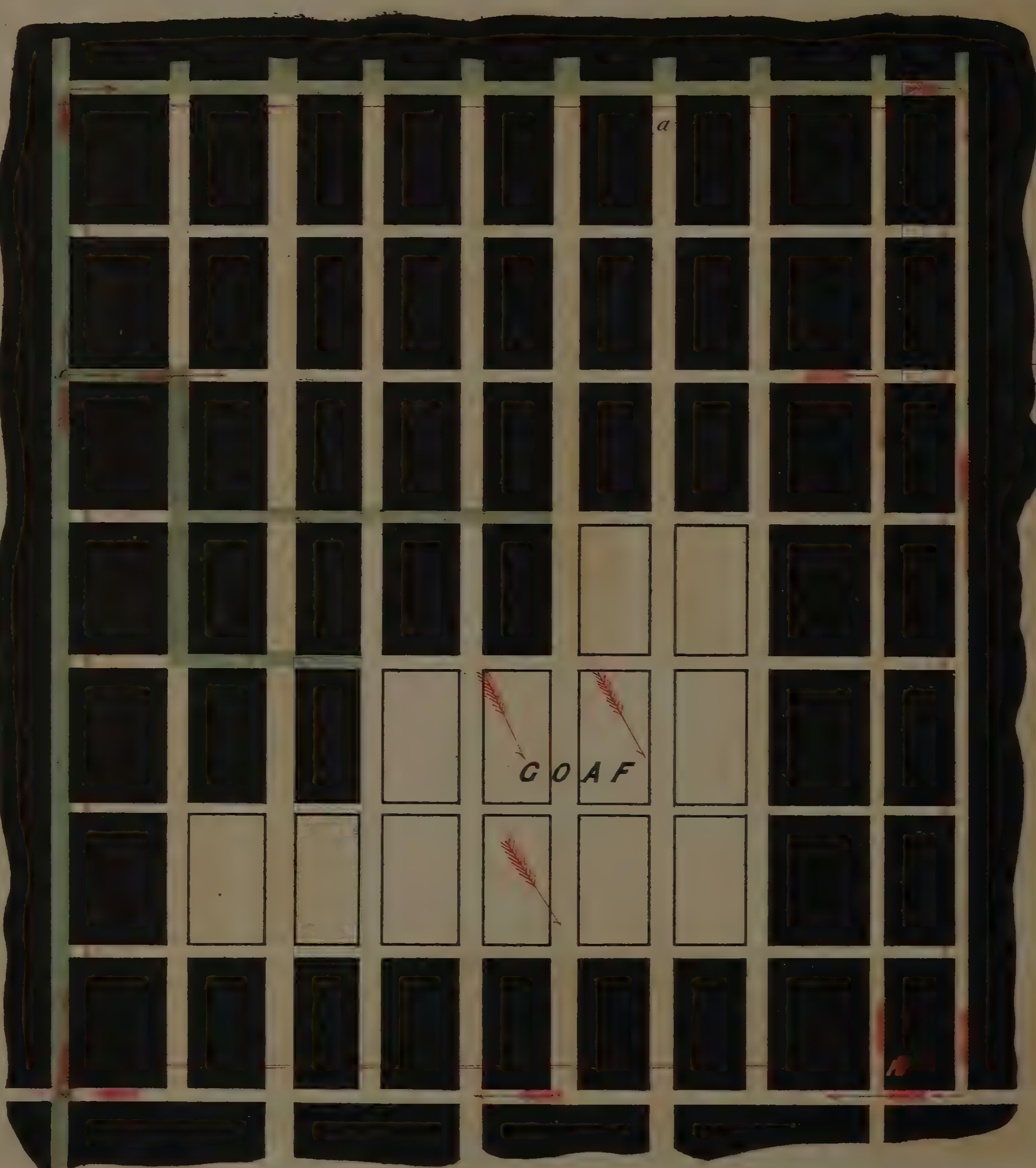
COAL WORKING IN THE WHOLE MINE FOLLOWED

G. C. Greenwell del.

Lamberts lith. Newcastle

PLAN
OF A SHETH OF BOARDS FOLLOWED BY
PILLAR WORKING,
The system of Ventilation pursued being improper and unsafe.

Fig. 1



The Arrows shew the course of the Air Currents

Shews a division of the Air — *Horse Road*

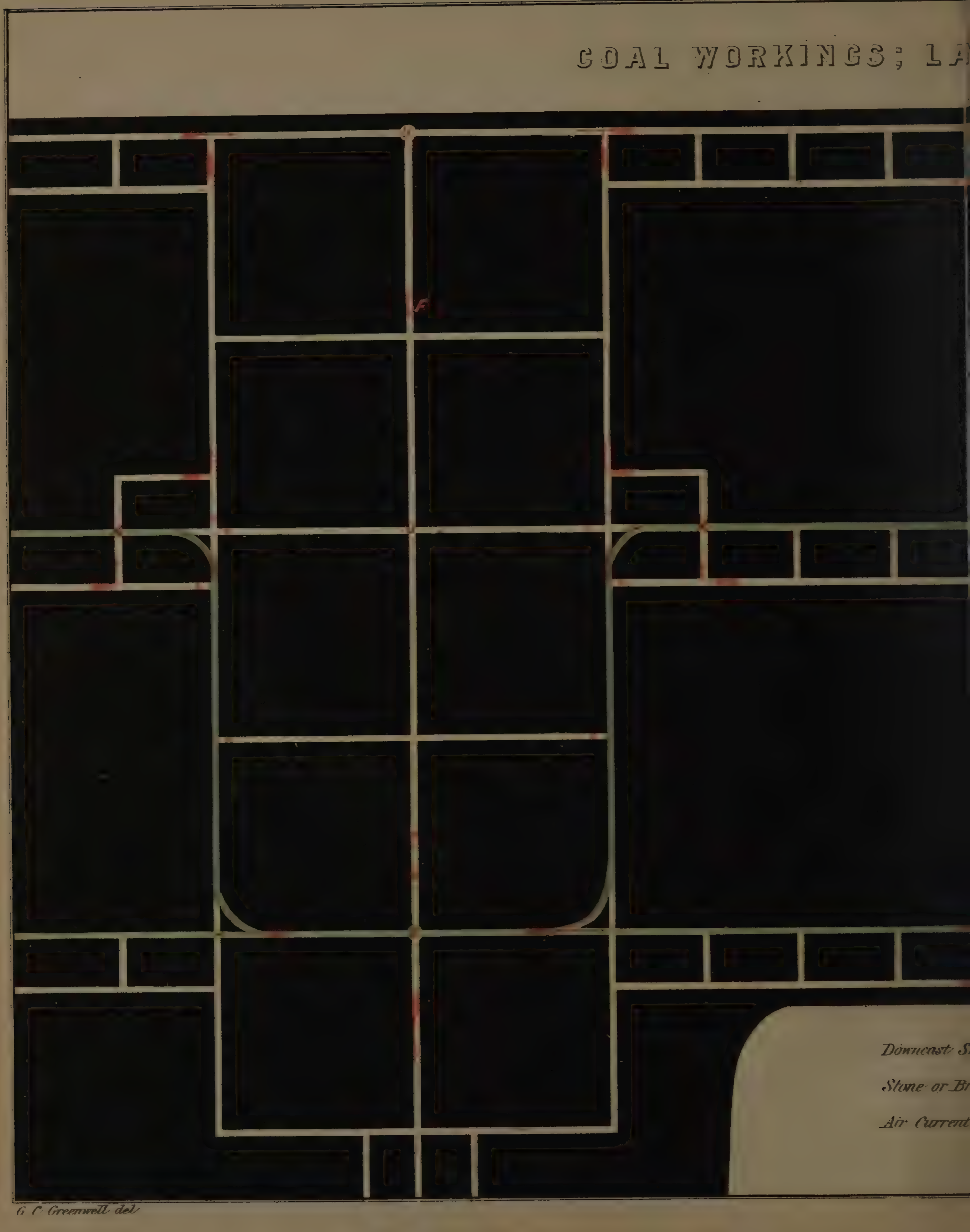
G. C. Greenwell del.

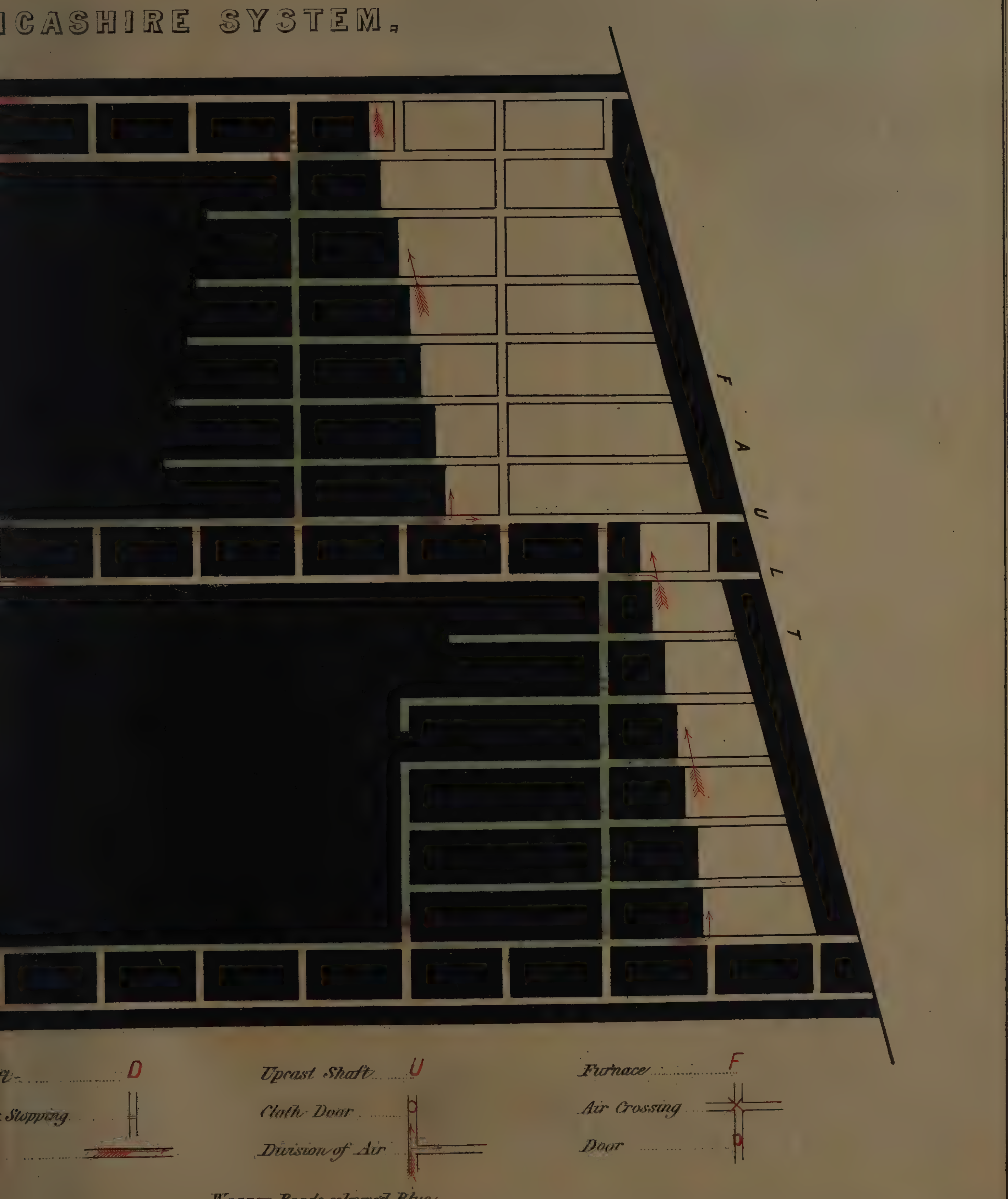
PLAN
OF A SHETH OF BOARDS FOLLOWED BY
PILLAR WORKING,
Under a proper and safe system of Ventilation.

Fig. 2.

A Brattice Stopping — Crossing

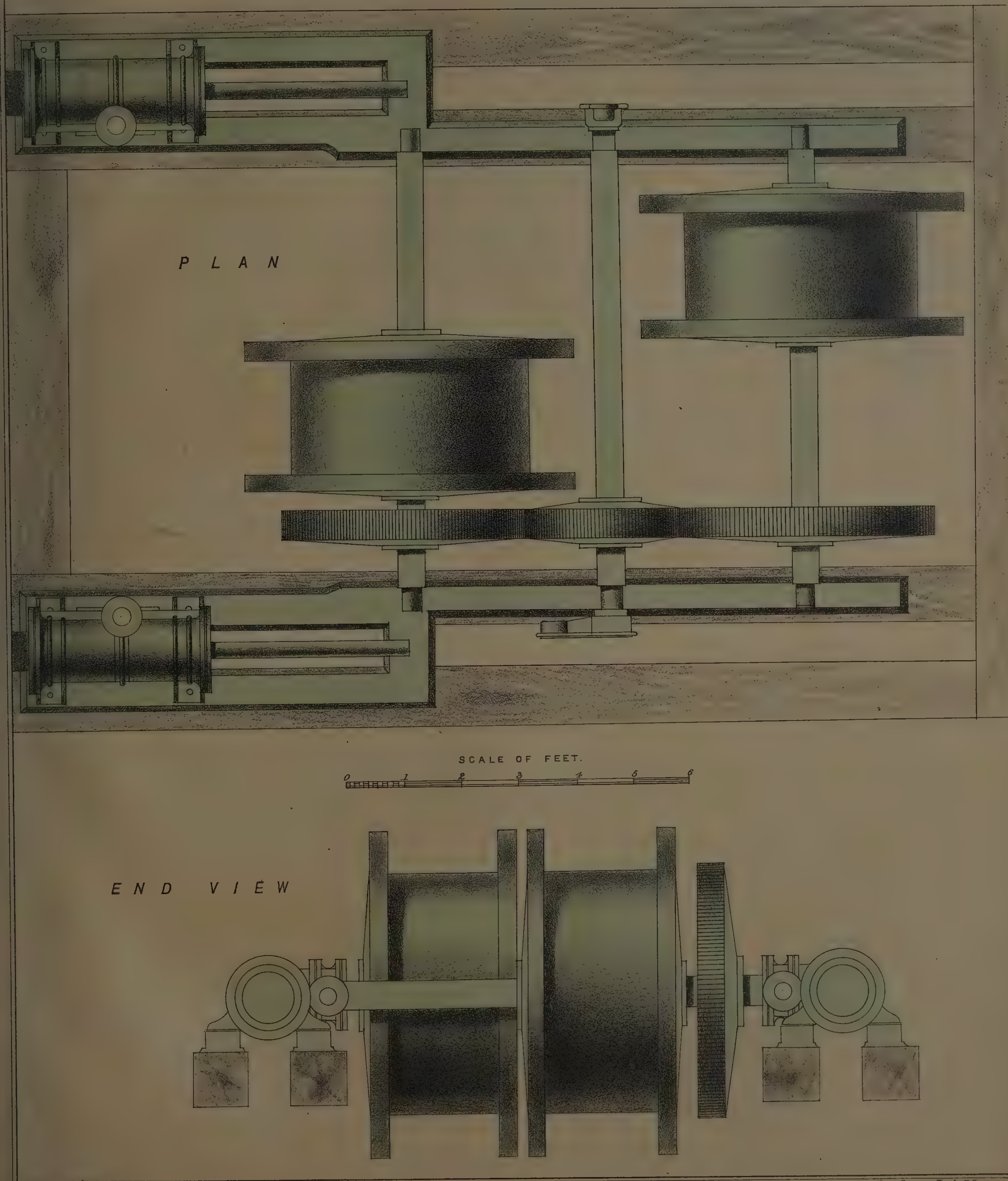
A Stone Do. — Regulator


COAL WORKINGS; LA
F
Downcast S
Stone or Br
Air Current
G. C. Greenwell del.



Lamberts lith^s Newcastle

PLAN AND END VIEW OF AN UNDERGROUND HAULING ENGINE OF 20 HORSES' POWER.



G. C. Greenwell del.

Lamberts Lith, Newcastle

VENTILATIN

Fig. 1.

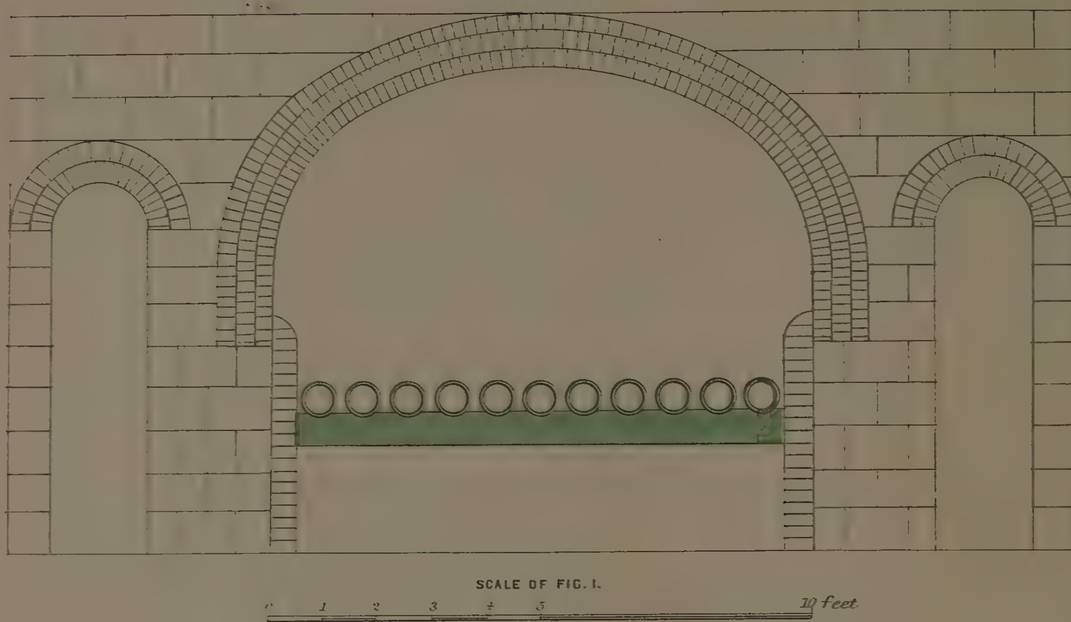
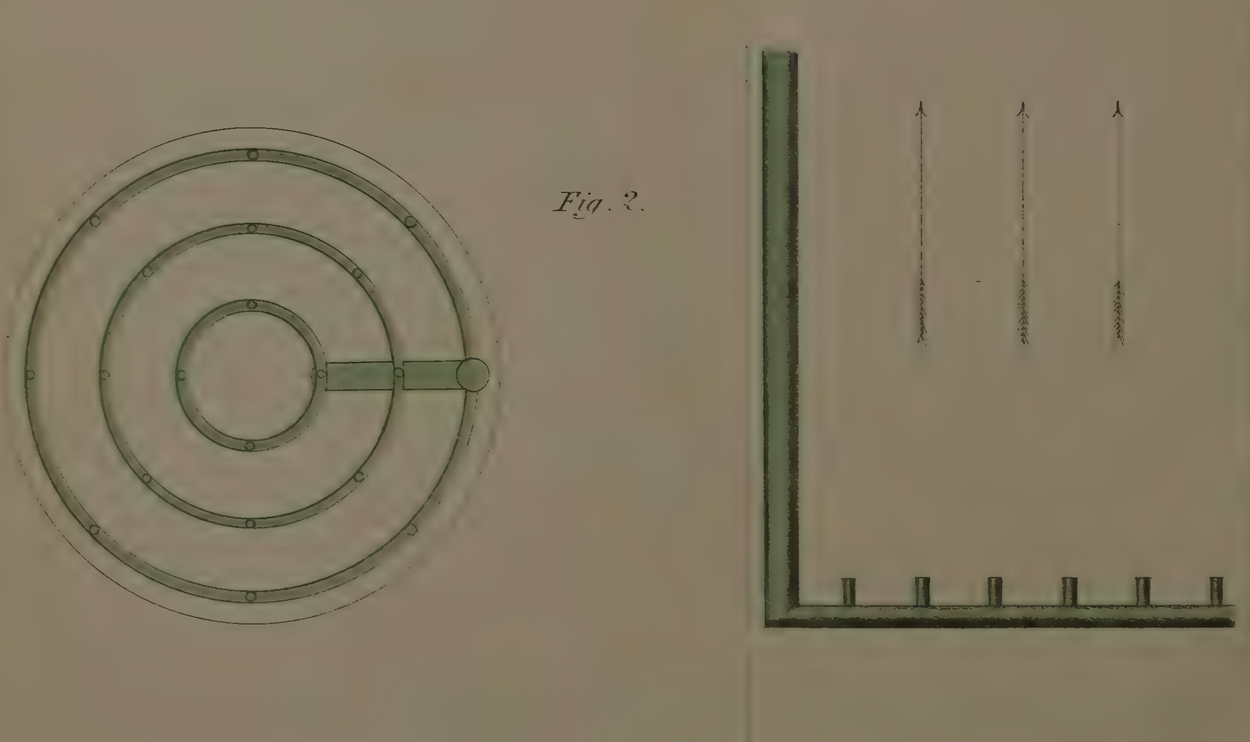


Fig. 2.



G.C. Greenwell del

APPARATUS.

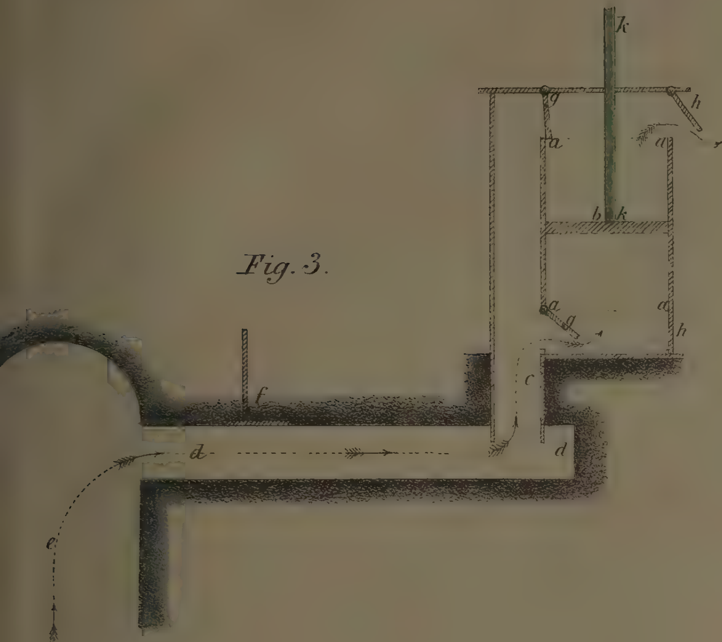


Fig. 3.

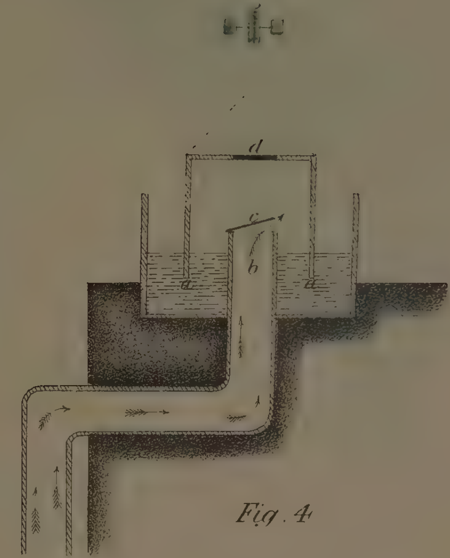


Fig. 4.

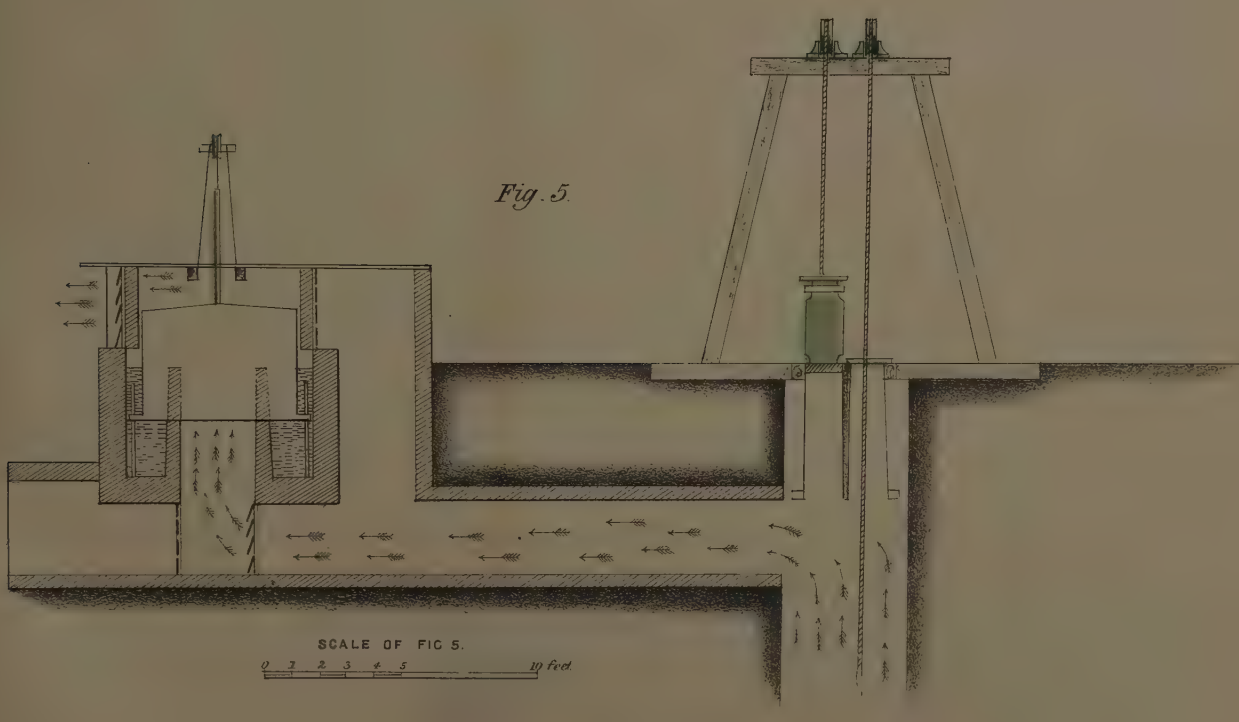


Fig. 5.

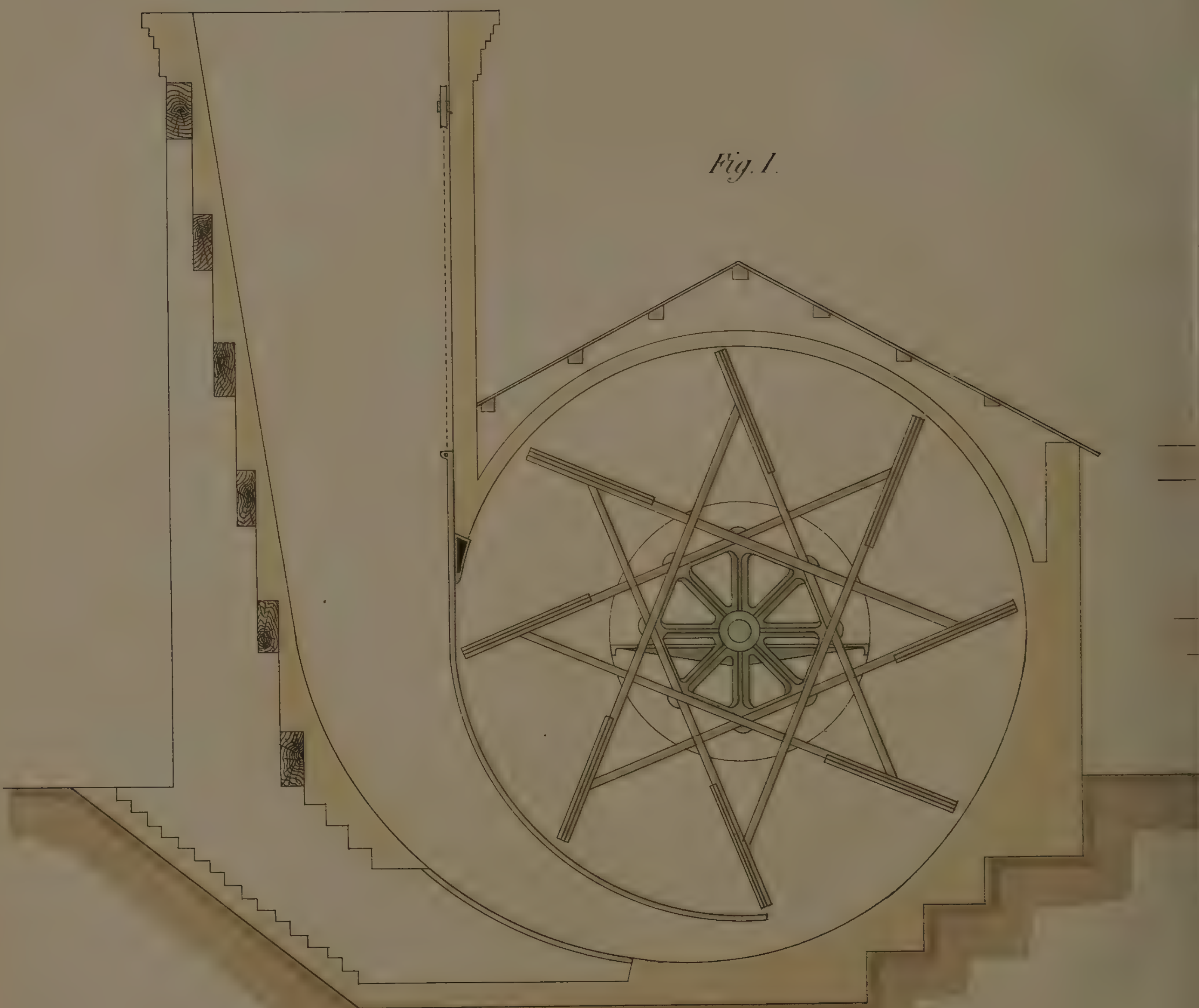
SCALE OF FIG 5.

0 1 2 3 4 5 10 feet

Lamberts Lith Newcastle

VENTILATING

Fig. 1.



SCALE OF FIG. I.

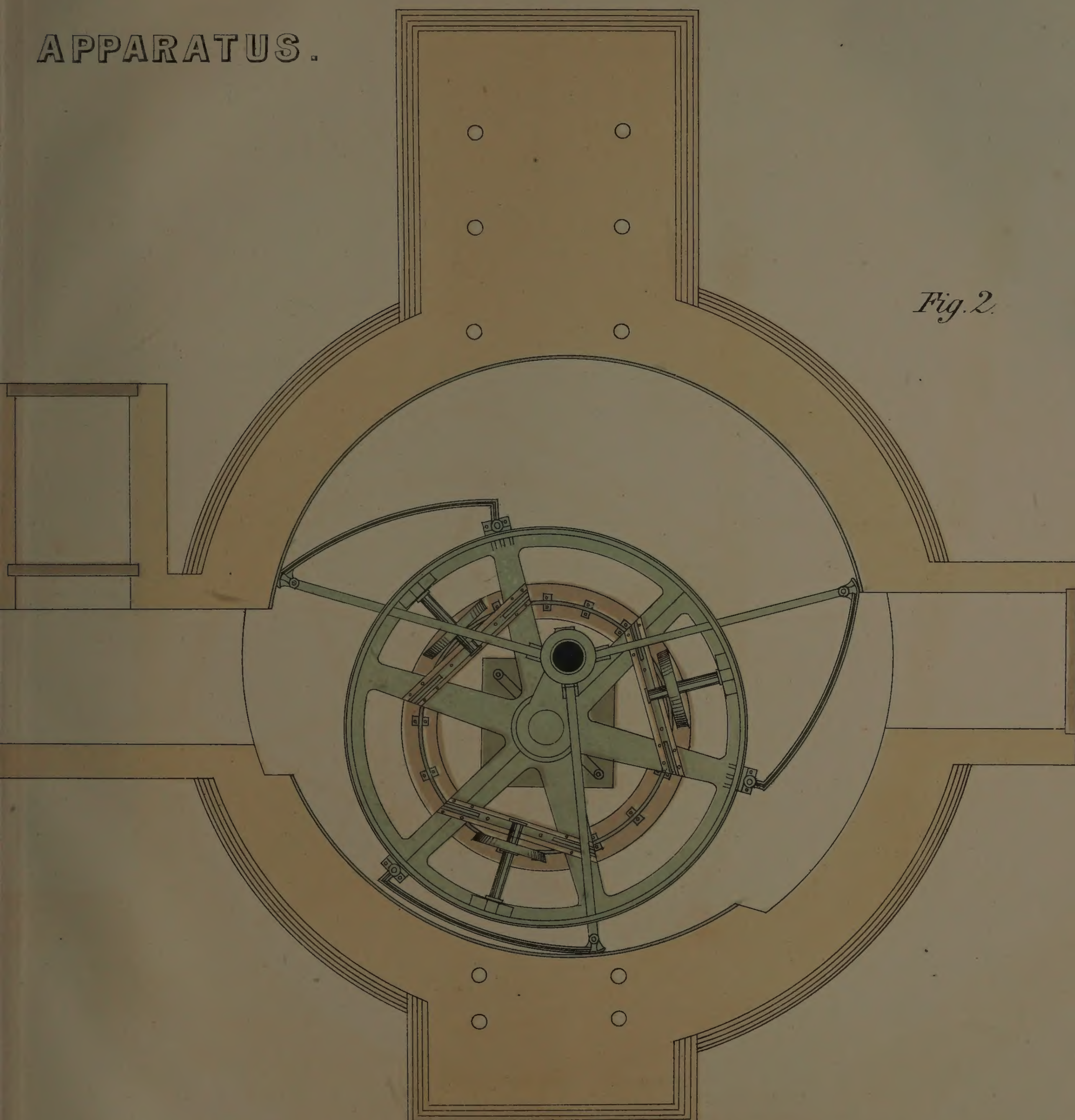
0 1 2 3 4 5 10 15 20 feet.

(From Burat's "Supplement au Matériel des Houillères")

G. C. Greenwell del.

APPARATUS.

Fig. 2.



SCALE OF FIG. 2.

0 1 2 3 4 5 10 15 feet.

(A. L. Steavenson, Transactions of North of England Inst. of Mining Engineers, Vol. 18)

Lamberts lith. Newcastle.